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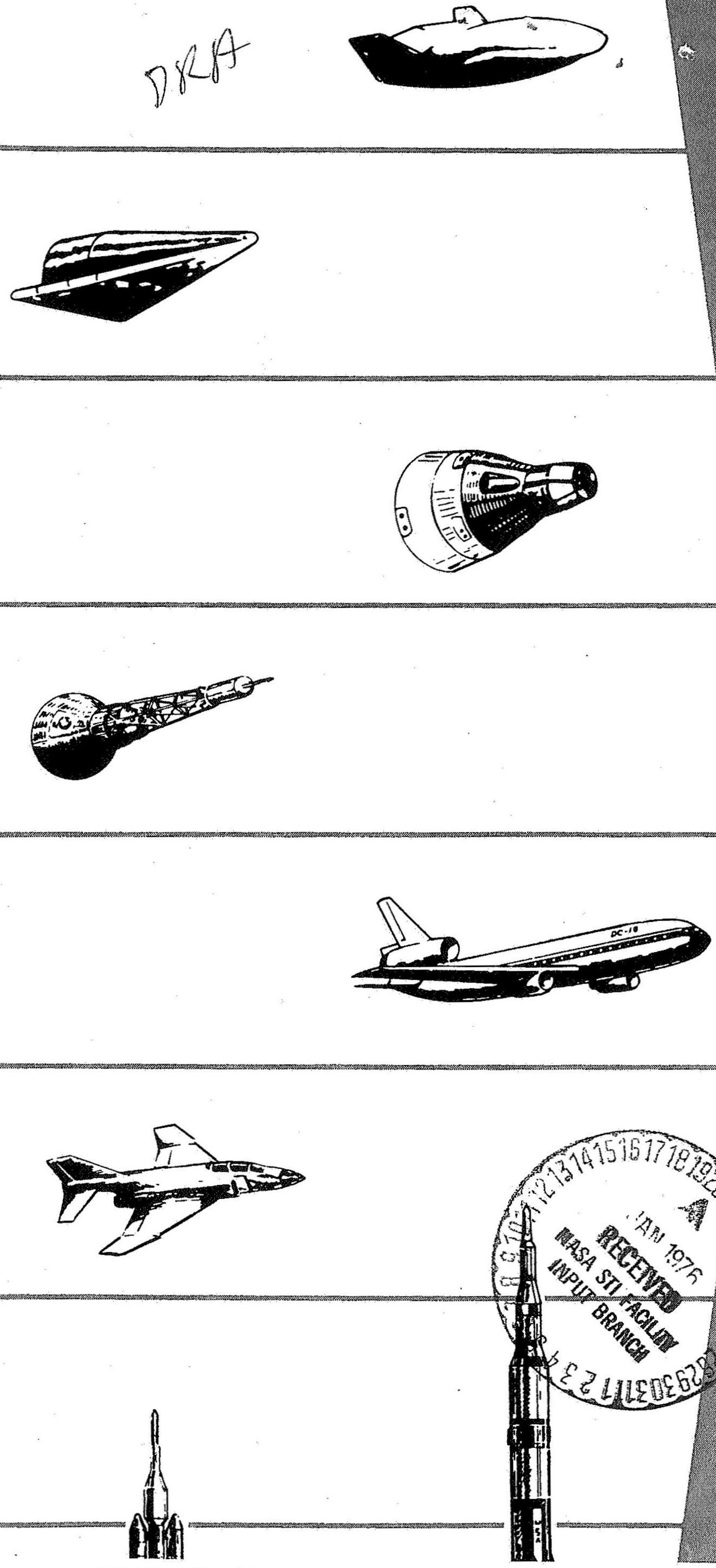

MDC E0308

Phase B System Study
FINAL REPORT

Part III–5 (B)
PROGRAM ACQUISITION PLANS

TEST

HIGH VALUE

SPACE SHUTTLE

LOW COST

MCDONNELL DOUGLAS
CORPORATION

MARTIN MARIETTA DENVER DIVISION

TRW SYSTEMS GROUP

PAN AM

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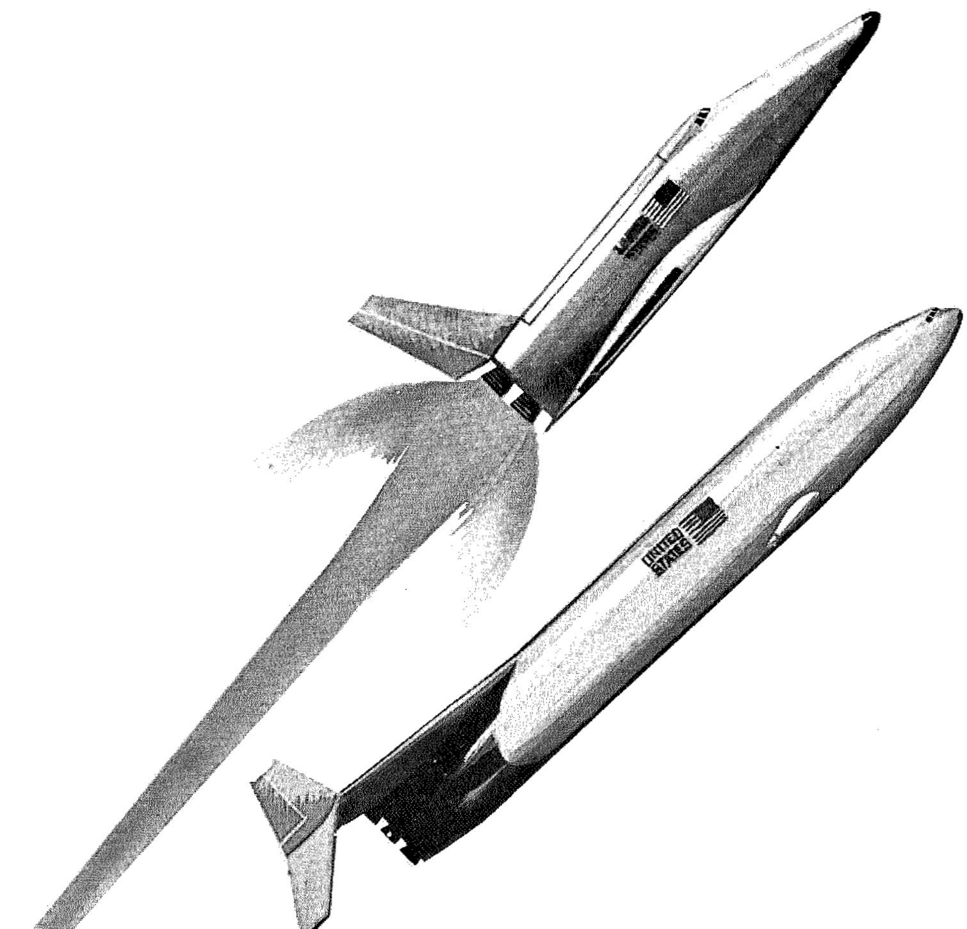
30 JUNE 1971

Space Shuttle System

PHASE B STUDY FINAL REPORT

Part III- 5 (B)
Program Acquisition Plan

TEST



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MCDONNELL DOUGLAS CORPORATION

MARTIN MARIETTA DENVER DIVISION

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FOREWORD

Introduction and Summary - The requirements necessary to conduct a Phase C/D program leading to an operational Space Shuttle System, and the McDonnell Douglas Corporation Team approach to implement them are defined in seven Program Acquisition Plans. By report numbers, they are:

MDC E0308 - III -

1 Program Management

2 Engineering and Development

3 Operations

4 Facility Utilization and Manufacturing

5 Test

6 Logistics and Maintenance

7 Cost and Schedule Estimates

The Program Management Plan impacts all of the other plans, by establishing the procedures and management activities for the entire program. Second in order of impact is the Engineering and Development Plan, which defines design and development effort and leads into manufacturing, test, and operation discussions, each in its own volume. The facilities section of the Facilities Utilization and Manufacturing Plan supports the Manufacturing, Operations, and Test Plans by identifying and defining the facilities required. Support requirements, in terms of maintainability, maintenance, logistics engineering, material support and control, supply control, packaging, and handling and transportation are defined in the Logistics and Maintenance Plan. Finally, the Program Cost and Schedule Estimates Plan describes cost/schedule activity and cost analysis methods for the total program.

As applicable, the plans are further categorized into Space Shuttle, Booster, and Orbiter. The following baseline assumptions and ground rules were employed in the Phase B study and are reflected in the plans:

Configuration - To facilitate timely, cost-effective implementation, all plans were developed independent of configuration, wherever practical. Where it was necessary to consider specific configurational aspects, the May 1971 MDC Space Shuttle was used. This configuration is outlined below, along with the other guidelines and assumptions used:

- o Delta Orbiter
- o Canard Booster
- o 550,000 lb thrust main engines
- o 1100 nm across range capability
- o Two-stage, fully reusable vehicle/system
- o Maximum payload capability of 65,000 lb launched due east
- o Airbreathing engines burning JP fuel

Phase C/D Management and Organization

- o Two vehicle contractors (Booster and Orbiter) are each contracted and managed by one of two NASA centers. A Vehicle System Integration Activity (VSIA) type organization is responsible for the integration of the Space Shuttle System, and delegates integration tasks to one or the other NASA Center/Vehicle contractor combination.
- o Innovative management techniques and new ways of doing business to minimize program cost are stressed.

Operations

- o The major horizontal flight testing will be conducted at EAFB.
- o Final assembly and operational launches (including vertical launch and horizontal shakedown flight test) are conducted at KSC.

- o The operational fleet consists of four Orbiters and three Boosters
- o Operational life is 10 years

Schedule

- o First horizontal flight - June 1976
- o First manned orbital flight - April 1978
- o Operational phase initiated - July 1979

The remainder of this foreword provides synoptic overviews to this and the remaining six Program Acquisition Plans. The purpose of the overviews is to offer the reader of this plan an insight into the content of the remaining plans.

PROGRAM MANAGEMENT PLAN
(MDC E0308-III-1)

The Program Management Plan defines management requirements and procedures which will permit the contractors, under NASA guidance and direction, to design, build, test, and develop a Space Shuttle System. The plan identifies and describes management activities essential to the conduct of the program. Key issues facing management and the interrelationship of these issues with cost, schedules, and technical performance lead into the Work Breakdown Structure (WBS), management organization, commonality implementation, and management techniques. The WBS, and a detailed definition of the products and services related to the individual WBS elements, is presented.

Organization of the contractor's corporate structure and the Space Shuttle Program team are discussed, and organization charts presented. Management contacts and interrelationships among MDC, NASA, teammates, and subcontractors are discussed. Such discussion includes approaches for conducting the necessary reviews and meetings, techniques for communication processes, procedures for interface control documentation for hardware-to-hardware interfaces and joint operating agreements for establishing and recording working relationships between contractors.

The commonality implementation section describes such concepts as the use of similar or interchangeable parts, as well as the economies inherent in common design approaches, similar technical depth, shared test and analytical results.

Management techniques, including the MDC Management Information System, which plans, controls, and provides visibility into project and functional cost and schedule performance within the WBS framework, are presented. Configuration management procedures discussed include identification, control, and status accounting for the baseline configuration and changes thereto.

PROGRAM MANAGEMENT PLAN
(MDC E0308-III-1)

The approach to data management, vehicle acceptance, traceability, make or buy, and subcontract management are presented as part of the management techniques section.

The appendix outlines the approach to three alternate MDC-suggested contracting options and compares these options with the baseline.

ENGINEERING AND DEVELOPMENT PLAN
(MDC E0308-III-2)

This plan defines the requirements for the total engineering effort involved in the design of the Space Shuttle System and the approach to implement these requirements. The plan is divided into three sections: Shuttle Systems, Booster, and Orbiter.

Shuttle System - The Space Shuttle section contains only that engineering and integration effort required for the analysis, development and test of the mated configuration. Policy activities, such as critical program categories and commonality control (which would be implemented through a NASA/VSIA-type activity) are also included. Those activities that are involved with the management, engineering, integration, assembly and test of the separate Boosters and Orbiters are included in their respective sections.

Following a discussion of the criticality categories approach and the approach to, and control of, commonality, the management approach for the Space Shuttle is discussed using the VSIA-type organization baseline.

Detail design and development activities include describing the physical and performance characteristics of the Shuttle, critical design analyses (such as boost phase analysis, off-nominal performance evaluation, separation analysis, and abort techniques), and design optimization and effectiveness analyses.

System integration activities include discussions of requirements analysis and allocation, trade study identification for those trade studies to be refined in Phase C, and development of criteria documents to group those criteria for each system and subsystem into a working document.

Test requirements are discussed for the various categories of ground and flight tests to which the Space Shuttle will be subjected. These include tests of the separation system, EMC tests, wind tunnel and dynamic tests of the mated

ENGINEERING AND DEVELOPMENT PLAN
(MDC E0308-III-2)

configuration, and vertical flight tests.

Finally, ground support equipment (GSE) critical areas and development problems are discussed and a development schedule presented.

Booster and Orbiter Systems - The Booster and Orbiter sections define the engineering and development requirements, and the approach to implementing these requirements, in the design and development of the Booster and Orbiter and their associated support equipment.

Management procedures, including organization; planning and control; schedules; key engineering activities that affect the timely completion of the design and development; and logic networks are discussed. The section on manpower describes the procedure for making engineering manpower forecasts by work breakdown structure for each engineering discipline and department.

The approach to configuration management, consisting of configuration identification, control and accounting is detailed. A discussion of data management addresses planning for interface control, document control, and program and design review. The role of the Interface Control Working Group (ICWG) and the application of interface control logic are outlined.

In the contingency planning and analysis section, the approach to making allowances for off-nominal task results and resource expenditures is discussed. System engineering and integration is concerned with design studies and analyses for system sizing and design refinement, and with trade studies to refine subsystem development and performance, resolve key issues, and explore growth potential. Major interfaces are defined, and the interface control plan discussed.

Sections 2.3.2.4 (Booster) and 2.3.3.4 (Orbiter) encompass a detailed discussion of subsystems development, including airframe, propulsion, avionics, crew station, and power supply groups.

ENGINEERING AND DEVELOPMENT PLAN
(MDC E0308-III-2)

These sections describe each subsystem, potential problems in its development, the approach to design, development, and test, and a development schedule for each subsystem.

The GSE development section discusses the engineering and design approach and acceptance test requirements. Major test articles, simulators and mockups required for Orbiter and Booster development, are described and the purpose of each test defined.

Design and development support requirements from safety, reliability, maintainability, human factors, materials and processes, and design services are discussed, and support activity scheduled.

OPERATIONS PLAN
(MDC E0308-III-3)

This plan defines the requirements for Space Shuttle, ground and flight operation and the MDC approach to implementing those requirements.

The requirements section of this plan is subdivided into Space Shuttle System, Booster, and Orbiter, and contains both ground and flight requirements. The paragraph (or paragraphs) of the approach section pertaining to these requirements is noted. Such notation provides traceability between the requirements and approach sections.

The approach section of the plan is divided into ground and flight operations. Ground operations include the activities from landing rollout through launch. The flight operations section includes activities from liftoff through landing.

The ground operations section discusses the activities from acceptance testing through the launch phase. Turnaround cycle activities are described in detail. This cycle consists of postlanding, maintenance, prelaunch, and launch activities. In addition, detailed timelines of these activities are included. Other activities pertinent to ground operations, such as operational facilities and activation, rescue capability, hold/recycle capability, alternate landing sites (and others) are also addressed in this section. Also included are the activities associated with the development flight test program, both horizontal and vertical.

The flight operations section discusses the anticipated missions and includes timelines and sequence-of-events charts. The mission operations systems, as well as mission control functions, are described, as are such activities as landing operations, aborts, and crew training. Such other operational interfaces as tracking and data relay satellite, experiments, and the scientific community are addressed in this plan.

FACILITY UTILIZATION AND MANUFACTURING PLAN
(MDC E0308-III-4)

The Facility Utilization and Manufacturing Plan:

(a) provides clear definition of the Government owned and Contractor facilities required to support the Space Shuttle Phase C/D program; and

(b) describes the manpower, material, and facilities needed to plan, manufacture, and functionally test flight hardware and (GSE).

The summary section includes a discussion of the rationale for facility site selection based on two factors:

(1) the chosen operational site for the Shuttle and

(2) the transportation problem posed by the size of the Booster and Orbiter vehicles.

Considered in the plan are evaluations of candidate launch sites, and sites for final assembly, propulsion tank fabrication and subassembly, fuselage manufacturing and assembly, and horizontal flight test.

The remainder of the facility section is devoted to discussing and defining the operations support characteristics of the KSC facility, which based on the selection rationale, was chosen as the operational site.

The appendix summarizes management and control procedures, including planning, scheduling, tooling, and control. The tooling philosophy and approach for manufacture of the Space Shuttle is, basically, to minimize construction of major fixturing, thus, minimizing costs. The assembly of the Orbiter main fuselage, which utilizes the main propulsion tank as a tooling base on which to build the main fuselage, provides a good example of the MDC philosophy. The Booster manufacturing approach employs existing major tooling and fixtures by adaptation and usage of Saturn tooling and G.S.E. The modular approach to the manufacture of vehicle major assemblies is emphasized.

FACILITY UTILIZATION AND MANUFACTURING PLAN
(MDC E0308-III-4)

Major manufacturing problems, and their proposed solutions, are presented and discussed. These problems are categorized, as applicable, by Booster and/or Orbiter.

The long lead requirements are listed and in the discussion of the respective assemblies the description of the manufacturing sequence tests, tooling and facilities requirements, schedules and cost estimates therefore as well as the rationale for each of the selections and decisions made.

LOGISTICS AND MAINTENANCE PLAN
(MDC E0308-III-6)

This plan presents the MDC logistics and maintenance approach, which will provide an integrated support program from the design phase through the operational phase. The plan consolidates all individual logistics support elements into an interrelated, interfaced, and program-phased activity. Included in the plan is a milestone chart which provides for timely and adequate identification, development, and scheduling of the logistics support requirements.

As nearly as possible, reusable Space Shuttle logistics and maintenance functions have been related to present airline practices which have been developed through extensive operating experience.

The plan is organized (in format) by functional activity. Each function, i.e., maintenance, technical publications, etc., is presented as an identifiable entity within the Logistics and Maintenance Plan.

PROGRAM COST AND SCHEDULE ESTIMATE PLAN
(MDC E0308-III-7)

This plan provides cost and schedule planning data which can be used for making decisions vis-a-vis the development and operation of a two-stage fully reusable Space Shuttle. The required data consist both of the costs for each part of the system, and of time phasing of these costs to establish funding requirements.

This report covers the development activities starting with Phase C of Phased Project Planning (PPP) through completion of a ten-year operational cycle. The traffic model assumed for the operational cycle was specified by NASA for this project. The costs to be used for GFE items (main engines) were provided by NASA.

These data are organized as required by DRD MF003M, which defines the specific data to be included. Four data forms are required which provide a complete breakdown of cost, schedule, and technical characteristics data, organized to the work breakdown structure and reported at Level 5.

The first section provides cost information on Cost Estimate Data Form A. This data form includes cost estimates, the time phasing recommended to spread the cost estimates for funding purposes, and the data necessary to derive unit costs for recurring items. Separate cost estimates are presented for nonrecurring (RDT&E) activities, recurring production activities, and recurring operations activities; non-recurring costs through first Manned Orbital Flight (MOF) are also presented.

The next section presents Data Form B, with detailed cost estimates divided across specific subdivisions of work for each WBS item. The subdivisions of work encompass design, test, tooling, production, and materials and subcontracts.

The technical characteristics data presented in Data Form C are a concise summary of the performance, sizing, and complexity parameters used in estimating the cost of each item of the WBS. Some other vehicle parameters have also been included to provide a more comprehensive description of those Shuttle technical, physical, and mission characteristics which are important in understanding the costs.

Data Form D presents the fiscal funding requirements for RDT&E, production, and operations activities.

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SECTION B

BOOSTER

1. INTRODUCTION

This section presents the plans for the development and verification testing of major Contract End Items (CEI) and their subsystems as defined to level 5 of the Work Breakdown Structure. The test approach described here is relative to the detailed requirements for test (Section 4) of the System and Subsystems specifications design requirements (Section 3).

Component development and qualification testing is recognized as an integral part of the test program, and is addressed in subsystems test descriptions. However, since the work depth of these plans are concerned with subsystems development and integration, combined subsystems testing, and horizontal flight testing of the completed vehicle(s), the detailed component test activity is not described.

Pre-delivery flight acceptance testing concerns the verification of specification compliance of the completed vehicle and provides pertinent data to support certification of compliance required by the NASA for delivery of the Contract End Item.

2. BOOSTER TEST PROGRAM SUMMARY

Flight Characteristics - The Booster mission will be verified throughout the entire performance envelope which includes: Boost phase, separation, re-entry, aerodynamic regime recovery, cruise back, and landing. Pertinent to the task will be the utilization of wind tunnels to evaluate the baseline configuration from the aerodynamic, thermodynamic, air loads, structural dynamics, and cruise subsonic propulsion. Approximately 67,700 wind tunnel occupancy hours will be programmed to substantiate the allied technology design considerations, of which 28,200 hours are Booster-oriented, and 12,100 are for the mated configuration.

Flight simulation studies will include pre-flight through landing phases of the primary mission and the ferry mission requirements, and will provide valuable evaluation of the man-vehicle systems interface and resulting crew station configuration and controls/display arrangement. Man-in-the-loop flight simulations accomplished on the MDC fixed base simulator will provide early evaluation of handling qualities and operational procedures. Full-scale physical mockups will be used to evaluate the habitable vehicle areas.

Booster flight verification testing will be accomplished by a two-part program: The horizontal flight tests will verify vehicle characteristics and subsystem operation in the cruise back, landing and ferry flight mission phases; functional evaluation of subsystems utilized in the ascent, entry, and separation phases of the mission will be evaluated during the conduct of the vertical take-off mated tests at KSC.

Figure 2-1 presents the complete listing of major test articles to be utilized in the conduct of Phase C/D testing.

Subsystem Testing - Airframe testing will be accomplished by subjecting critical sections to vigorous ground testing while conducting only nondestructive loadings on the completely assembled flight airframe. Sectionalized testing of selected assemblies allows overall program progress even though structural anomalies should occur. Fatigue testing per se is not anticipated. Safe life demonstrations, however, will be performed at the section assembly level. Structural dynamics considerations will be integrated with the main propulsion system integration tests. To enhance understanding of structural dynamics of the mated vehicles, it is proposed to utilize dynamically scaled model tests and to confirm these findings by conducting low level nondestructive dynamic response tests on the assembled flight vehicle. Thermal Protection System tests will be conducted on representative TPS or TPS related subassemblies. These evaluations will involve strength, resistance to thermal and acoustic environments, aerodynamic erosion, and leakage. Approximately 20 percent of the TPS subassemblies will be subjected to these tests.

All propulsion system components will be subjected to qualification tests to show specification conformance. The integrated propulsion system will be tested, installed in the second production vehicle, minus the wings and empennage, canards and airbreathing engines, and horizontal cockpit displays. Other non-main propulsion system items may also be omitted because of schedule or cost considerations. The test article will be used to develop and verify characteristics of the main and ACPS tank loading techniques, feed systems, the performance of the APU subsystem, main tank pressurization, pressurization and venting, the vehicle pneumatics, hydraulics, and the integration of the avionics monitoring and control of these subsystems.

The airbreathing engines testing will be conducted oriented toward assuring the capabilities of the fuel system and other concerns assuring the integration of the engines into the canard and its air ingestion and jet flap elements. Fueling, defueling, transfer and feed tests will be accomplished on a test rig capable of being oriented in the horizontal or vertical positions.

The auxiliary power unit tests will demonstrate control capability under varying hydraulic and electrical demands. In addition, independent combustor operation will be demonstrated. The effects of the operating combustor on the non-operating combustor will be identified. Single-component failure effects will be demonstrated.

The vehicle avionics group is composed of these subsystems: Guidance and navigation, flight controls electronics, data management, communications and navaids, controls and displays, and software. These subsystems will be subjected to line replaceable unit development and qualification, subsystem development and integration, and finally the complete avionics as an integral setup, the ASTU.

The Environmental Control and Life Support system (ECLS) and the crew systems comprise the crew station group. Crew systems tests will be directed toward evaluation studies of crew-to-vehicle subsystem interface which includes human factors aspects of the crew station itself, the crew escape system and procedure, and controls and displays. The ECLS test setup will be utilized in the man-to-machine relationship evaluation directed toward bodily comfort and life support. The environmental levels to be imposed on the ECLS during testing will be specified in an environmental design and test criteria document wherein environments will be established for various zones of the vehicle. Dedicated setups will be designed for each subsystem of the ECLS, e.g., cabin air, cabin cooling, equipment cooling, and fire extinguishing. Pertinent subsystems interfacing with ECLS will be simulated if actual interface proves by further study to be not cost effective. Environmental mission duty cycles will be imposed on the system for nominal and off-nominal conditions.

The MDAC-ED fixed-base flight simulation setup will be updated for C/D phase testing. Simulation studies to receive concerted dwell will cover pre-flight through landing in the primary mission, and ferry operations conditions for the secondary missions. Information gained during these tests will validate crew station flight instrumentation and control arrangements, and vehicle handling qualities and procedures. Tests will include normal and emergency modes. The One-"g" mockup will be used to enhance the fixed-base simulations studies, however, the static nature of the setup will permit detailed evaluation of control positions, location of instruments, cockpit view restrictions, and entrance and egress problems. Crew escape safety criteria requires that an off-the-shelf system be adapted for flight test. This system installation will be qualified by sled test even though the selected crew escape system should be a fully qualified system in other installations.

The power supply group is composed of the electrical power subsystem, the hydraulic power subsystem, and the power generating source, the APU's (described in propulsion subsystem testing above). Along with the effort involved in component qualification the subsystem tests will be designed to evaluate power distribution, dropouts, ripple high-potential resistance, and continuity. Hydraulic power testing involves the use of the hydraulic system "Iron Bird", an exact functional and spatial setup of the complete hydraulic system driving all components, which in turn operate the aero control surfaces, landing gear, and other mechanisms which will be loaded by simulation using springs, buffers, dash pots, and other devices to reproduce actual nominal and off-nominal loading conditions. In certain installations control surfaces and other moving parts may be dummied to provide the cost-effective aspect.

Combined Systems Testing - Combined systems testing for Shuttle will be conducted at the most economical level of assembly of subsystems considered from a size and/or facility constraint. These tests will be conducted utilizing the Main Propulsion Test Unit, the Avionics Systems Test Unit, the Hydraulics and Controls Test Unit (Iron Bird), the Environmental Control and Life Support Test Unit (although this assembly is not considered as a major setup), and the Flight Simulators (fixed base, crew station, and ingress-egress mock-ups). These test units were described in preceeding discussions.

Combination of the major subsystems will dwell on the evaluation of interaction characteristics. Where possible, from size and location considerations these interfaces will be manifested by metal-to-metal and wire-to-wire connections. Where this cannot be accomplished, simulators, and/or simulated systematic stimulations will be employed which will cause or duplicate the intended interface interaction. The use of ground support equipment as appropriate, in support of combined systems testing will provide the exterior interface link.

Vehicle Testing - Final integrated vehicle testing will be conducted on the flight vehicle. These tests include structural loading tests to calibrate instrumentation. These loads will be applied through fixtures designed to apply loadings through fail-safe interlocks to preclude structural damage. Dynamic response of the structure will be in a horizontal attitude with the airframe supported by low-spring-rate devices. Electromechanical exciters will provide the drive force for mode shapes and frequency response data.

Installed subsystems will be functionally tested individually and in combinations representative of true operative conditions in order to substantiate test information obtained from earlier component, subsystem, and integrated tests collected from activities on the major dedicated test setups. The purpose of these tests is to obtain final verification of installed performance under individual tests and in the interfaced configuration. System tuning and instrumentation calibrations will provide a firm data base for horizontal flight testing.

Horizontal airplane flight mode tests will provide performance data for the cruise-back, landing, and ferry mission phases. Development and verification testing will be integrated in the overall flight test approach. The flight verification of specification test requirements will be documented as it is attained. The horizontal booster flight test program will comprise 438 flight hours utilizing three boosters over a total period of 32 vehicle month activity. Testing will be conducted at Kennedy Space Center (KSC), Florida, and Edwards Air Force Base (EAFB), California.

Vertical flight testing will be conducted (mated with the orbiter) on boosters No. 2 and 3. The vertical flight test program is discussed in depth in Section A, Paragraph 7.5.

SUMMARY OF MAJOR GROUND TEST ARTICLES - BOOSTER

TEST ARTICLES	USES
(a) WIND TUNNEL MODELS (Reference paragraph 4.1 and Section A, paragraph 6.1)	Provide engineering data for use by aerodynamic, thermodynamic, loads, structural dynamic and propulsion technologies in developing, analyzing, and confirming the configuration and pertinent design aspects of the booster to perform its Space Shuttle mission from launch through landing and ferrying.
(b) MAN-IN-THE-LOOP FLIGHT SIMULATOR (Reference paragraphs 4.2 and 5.4.2)	Manned evaluations of interfaces with the vehicle and its systems and of handling qualities and procedures; covering pre-flight through landing phases of the primary missions and ferry operations.
(c) DYNAMICALLY SCALED MODEL OF BOOSTER STRUCTURAL ARRANGEMENT (Reference Section A, paragraph 6.2)	Provide structural dynamics transfer function data on mode shapes and frequencies and vehicle modal coupling for dynamic analysis of the launch configuration (tested with dynamically scaled model of the orbiter structural arrangement).
(d) MASS-INERTIA PLANAR MODEL OF VEHICLES SEPARATION SYSTEM WITH FORE AND AFT VEHICLE INTERCONNECTS (Reference Section A, paragraph 6.3)	Demonstrate functional, structural and dynamic adequacy of vehicles interconnect-separation system. Demonstrate life cycle capability of vehicle interconnects.
(e) ONE ASSEMBLY CONSISTING OF LEFT (OR RIGHT) SIDE WING AND FIN, AFT THRUST STRUCTURE AND WING CARRY-THROUGH (Reference paragraph 5.1.7)	Establish low level dynamic response characteristics and influence coefficients. Demonstrate structural adequacy for critical design conditions of reusability and ultimate strength.
(f) ONE MAIN LH_2 TANK ASSEMBLY (Not Insulated) (Reference paragraph 5.1.7)	Establish low level dynamic response characteristics. Demonstrate structural adequacy for critical design conditions of reusability and ultimate strength.
(g) ONE INTER-TANK SECTION WITH LEFT (OR RIGHT) SIDE CANARD ASSEMBLY (Reference paragraph 5.1.7)	Establish influence coefficients and low level dynamic response characteristics. Demonstrate structural adequacy for critical design conditions of reusability and ultimate strength.
(h) ONE MAIN LO_2 TANK ASSEMBLY (Reference paragraph 5.1.7)	Establish low level dynamic response characteristics including dynamic interaction of tank structure and liquid. Demonstrate structural adequacy for critical design conditions of ultimate strength.

FIGURE 2-1

TEST ARTICLES	USES
(i) ONE FORWARD FUSELAGE SECTION (Reference paragraph 5.1.7)	Establish low level dynamic response characteristics and evaluate acoustic transmission characteristics. Demonstrate structural adequacy for critical design conditions of ultimate strength.
(j) ONE LEFT (OR RIGHT) RUDDER ASSEMBLY (Reference paragraph 5.1.7)	Establish low level dynamic response characteristics and demonstrate compatibility with wing fin. Demonstrate structural adequacy for critical design conditions of acoustics environment and ultimate strength.
(k) ONE LEFT (OR RIGHT) ELEVON ASSEMBLY SET (Reference paragraph 5.1.7)	Establish low level dynamic response characteristics and demonstrate compatibility with wing. Demonstrate structural adequacy for critical design conditions of acoustics environment and ultimate strength.
(l) ONE EACH NOSE AND MAIN LANDING GEAR ASSEMBLY (Reference paragraph 5.1.7)	Establish low level dynamic response characteristics and develop metering pin characteristics. Demonstrate structural adequacy for critical design conditions of ultimate strength.
(m) TPS PANELS AND LEADING EDGE SEGMENTS (approximately equal to 20% of total TPS weight) (Reference paragraphs 5.1.6 and 5.1.7)	Establish joint compatibilities and/or leakages. Establish low level dynamic response and heat transfer characteristics. Demonstrate structural adequacy for critical design conditions of reusability (including acoustics) and ultimate strength.
(n) FUSELAGE SECTION OF FLIGHT VEHICLE WITH MAIN PROPULSION SYSTEM INSTALLATION AND 12 PROTOTYPE MAIN ENGINES (Reference paragraphs 5.2.1 and 6.4) Note: Interim use as test article that is returned to manufacturing for refurbishment and completion of assembly to become a flight vehicle.	Verification of the design and performance of the main propulsion subsystem and interfaces with other subsystems such as structure, electrical power, hydraulics - thrust vector control, and GSE.
(o) ATTITUDE CONTROL PROPULSION SYSTEM (ACPS) TEST UNIT (Reference paragraph 5.2.2)	Develop and demonstrate capability of the propellant storage and supply to be filled, drained and purged, and to supply liquids to propellant conditioning equipment. Demonstrate capability of the propellant conditioning, gaseous storage and distribution subsystem to receive liquids from the supply

FIGURE 2-1 (Cont.)

TEST ARTICLES	USES
	subsystem, pump them to high pressure, convert them to gas, store them in accumulators, and supply the engines, propellant conditioning equipment and other using sources on demand and within design tolerances.
(p) AUXILIARY POWER UNIT (APU) TEST UNIT (Reference paragraph 5.2.4)	Test in conjunction with ACPS Test Unit to demonstrate compatibility with the ACPS supplied propellants. Demonstrate compatibility with interfacing hydraulic, electrical power and avionics components. Demonstrate design capability to supply electrical and hydraulic power at all times.
(q) AIRBREATHING ENGINES SYSTEM (ABES) FUEL SUBSYSTEM TEST UNIT (Reference paragraph 5.2.3)	Demonstrate design capability to fuel the subsystem in the vertical and horizontal vehicle positions, to transfer fuel between tanks for proper center of gravity control, to supply fuel to the engines at required pressures and flow rates, and to pressurize the fuel tanks for maintaining internal pressure above external ambient pressure.
(r) SINGLE AIRBREATHING ENGINE/CANARD SEGMENT TEST UNIT (Reference paragraph 5.2.3)	Evaluate characteristics of different air start modes and effectiveness of the fire suppression system at altitude conditions.
(s) AVIONICS SYSTEM TEST UNIT (ASTU) INCLUDING ELECTRICAL DISTRIBUTION SUBSYSTEM (Reference paragraphs 5.3.1.3, 5.5.1, 6.1, and 6.2)	Integration of avionic subsystems and electrical power distribution including redundancy management; verification of design performance goals; development of avionic interfaces with other subsystems; development of operating, checkout, and servicing procedures.
(t) SOFTWARE VALIDATION COMPLEX (ASTU COMBINED WITH COMPUTATIONAL EQUIPMENT) (Reference paragraph 6.2)	Validation of horizontal flight, total mission and checkout software programs through closed loop hardware-software testing.
(u) CABIN AIR, CABIN COOLING, AND EQUIPMENT COOLING SUBSYSTEM TEST UNITS (Reference paragraph 5.4.1)	Integration of environmental control and life support subsystems including verification of performance, demonstration of failure tolerance, and development of operating, checkout, and servicing procedures.
(v) CREW ESCAPE SYSTEM SLED TEST UNIT (Reference paragraph 5.4.2)	Assure adequate design integration and operation of the crew escape system for horizontal flight test operations over the flight test envelope of dynamic pressures. (same test article used for orbiter with commonality of crew escape system)

FIGURE 2-1 (Cont.)

TEST ARTICLES	USES
(w) FLIGHT DECK CONTROLS AND DISPLAYS, LIGHTING, AND CREW ACCOMMODATIONS/INGRESS AND EGRESS MOCK-UPS (Reference paragraph 5.4.2)	Aid in design and human factors evaluation. Assist in crew systems integration including development and verification of procedures, crew training, and functionality and habitability.
(x) ELECTRICAL POWER DISTRIBUTION TEST UNIT (Reference paragraph 5.5.1)	Subsystem development and integration testing and testing of interfaces with other subsystems.
(y) HYDRAULICS AND CONTROLS TEST UNIT (HCTU) (Reference paragraphs 5.5.2 and 6.3)	Hydraulic subsystems development and integration. Integration of total hydraulic system including verification of design performance goals and demonstration of failure tolerance. Development and verification of interfaces with non-hydraulic systems, particularly flight control electronics. Development of operating, checkout, and servicing procedures.
(z) INTERIM USE OF FLIGHT VEHICLE(S) (Reference Paragraph 7.2 and Section A, paragraphs 7.2 and 7.3)	Calibrate flight test airframe instrumentation. Establish low level dynamic response characteristics. Verify integration of the installed subsystems (electrical, hydraulic, avionic/software, ECLS, ABES). Electromagnetic compatibility checkout. Flight readiness firing of main propulsion system.

FIGURE 2-1 (Cont.)

3. BOOSTER TEST GUIDELINES

The test program has been planned to support the booster first horizontal take-off flight schedule of June 1976. With an additional requirement for controlled funding during RDT & E, the test phases will be integrated to satisfy the maximum number of objectives during each test performed. Maximum use of each test article will be made and changes in test set-ups will be minimized. The integrated test plan flow is shown in Section A, Figure 2-1. The test philosophy and criteria applicable to the booster test program are essentially the same as presented in Paragraph 3.0 of Section A. The Equipment Qualification Plan (4.0), Equipment Acceptance Plan (5.0), Reliability and Quality Assurance Participation and Safety Considerations (8.0), and Test Program Management (9.0) of Section A are directly applicable to the Booster.

3.1 Purpose and Intent Guidelines - Booster testing will be performed only to the extent necessary and practical for obtaining engineering information needed to finalize the design of the booster and its supporting equipment, to supplement non-testing assessment methods in assuring compliance of the booster and its supporting equipment to specification requirements and to provide the level of confidence necessary to employ the booster in flight operations. The objective is to develop an operational vehicle system at substancially lower test cost in proportion to the total program cost than has been obtained in previous space programs. The test scheduling has considered the requirement to minimize the rate of expenditures to smooth out the cost outlays. Booster testing will be an integral part of the engineering and development program. The details and the timing of the efforts will be accomplished in consonance with program milestones, design and assessment activities, manufacturing activities, and facilities availability and utilization plans.

3.2 Guideline Objectives - The prime technical objectives of the booster's test program will be to assist the total engineering and development effort in:

- Establishing reasonable confidence in the ability of the vehicle to perform the Space Shuttle mission.
- Obtaining sufficient engineering data defining the operational capabilities of the vehicle to provide confidence in the design of the total vehicle and its supporting equipment.

The programmatic objectives shall be to:

- Make maximum practical use of flight-type hardware to obtain ground test data without impairing its subsequent use for flight operations.
- Utilize existing facilities with minimum modifications, or facilities that are justified for acquisition because they are needed in the operational phase.
- Employ test operations wherever practical to assist other program functions (e.g., training, maintenance, operational procedures and test methods).
- Attain maximum commonality of test activities applicability to both Space Shuttle vehicles.

3.3 Approach Guidelines - To further the program goals, the following general approach guidelines will be followed:

- Wind tunnel and simulation testing will be conducted as necessary to establish reasonable confidence in the capability of the configuration to satisfy program requirements.
- Airframe testing will be conducted in build-up-fashion at levels of assembly that will provide assurance of integrity with the minimum quantity of test articles.

- Operating subsystems and their components, software, and supporting equipment will be tested so that the levels of assembly used and the extent of emphasis placed on test vs assessment best comply with their criticality for safe and successful operation and their programmed initial flight usage time in the Space Shuttle System.
- Engineering information resulting from Phase B studies, Supporting Research and Technology (SR&T) program, and the Supplemental Major Structural Test program will be used to the maximum extent.
- Analytical techniques will be employed in the utilization of ground test data to provide reasonable continuity in the engineering and development program.
- The flight test program will be used to obtain data and experience that is impractical to obtain through ground testing because of inordinate expenditures for specialized or large scale test facilities. Additional approach guidelines are outlined in Figure 3-1.

BOOSTER TESTING APPROACH GUIDELINES

GUIDELINES	RATIONALE
Wherever practical, all testing shall be planned so as to satisfy the maximum number of objectives, and to allow use of the test data to satisfy full or partial verification of specification requirements.	Potential cost and time savings by eliminating testing redundancy.
Test requirements will be established from and correlated to design and operational performance requirements. The requirements will be defined in specifications and in design and test criteria documents.	This is required to provide requirements information for individual detailed test plans.
Verification testing shall be performed with test article interface conditions equivalent to vehicle installation conditions or analyically predicted vehicle values, unless impractical or differences can be adequately accounted for by analysis.	Required for valid correlation and evaluation of test results.
Component testing, subsystems testing, combined systems testing, and ground test of flight test vehicles shall be employed in build-up fashion to demonstrate and evaluate redundancy modes of operation. Special and dedicated reliability testing shall be performed by exception only.	This is in consonance with the desired systems design philosophy of the Space Shuttle and provides sufficient opportunities to determine design compliance without incurring the cost of extensive reliability testing.
GSE required to support ground and flight test will be operational items to the maximum extent possible. GSE which cannot be design accelerated to meet the test schedule will be identified and suitable prototype or special equipment will be used.	Maximum program cost benefits, as well as usage experience benefits, can be derived from using hardware needed in the operational phase to fulfill RDT&E requirements. The creation of specific GSE for the short-term usage in the RDT&E phase is not cost effective.

FIGURE 3–1

BOOSTER TESTING APPROACH GUIDELINES

GUIDELINES	RATIONALE
Hardware that is critical to accomplishment of flight test objectives, or the safety considerations, will be qualified to selected environments, either by test or assessment, prior to usage. Hardware "Operational Criticality Categories" (Section A, Paragraph 3.1) shall be used as guidelines for determining priorities, test emphasis, and the allowable degree of qualification by non-test (assessment) methods.	Required to provide for reliability and safety, and for item verification to specification requirements.
Equipment qualification (certification for flight) verification (test or assessment) shall be based on anticipated operational environmental conditions as defined in item specifications.	Required to validate equipment items for test or operational usage.
Each hardware item, or component, to be used in qualification tests shall first satisfactorily meet quality assurance inspection and acceptance and functional test requirements as specified in the pertinent item specification.	To assure physical adequacy of qualification test articles with respect to flight hardware design.
Wind tunnel test data shall be appropriately formatted, reduced and promptly made available to the agent specified by the procurement activity for introduction to the SADSACK data bank system.	To provide NASA and the vehicle contractor(s) with necessary engineering information for timely performance of interfacing technical activities.
Structural test conditions shall be identified as "static" for incremental load applications, "transient" for load-time relationships, and "dynamic" for oscillatory loadings.	To provide for uniformity in terminology.
Structural test conditions and levels shall be identified consistent with the Space Shuttle Structural Loads Report (TBD).	To provide for uniformity in terminology.

FIGURE 3–1 (Cont.)

4. FLIGHT CHARACTERISTICS

Description of Configuration and Mission - The booster configuration and operational performance/requirements are basic factors in the formulation of the Phase C/D wind tunnel, flight simulation and in-flight verification test plans presented in subsequent Sections 4.1, 4.2 and 4.3, respectively. Figure 4-1 presents the booster reentry profile and other performance characteristics evolved during the Space Shuttle Phase B studies.

SUMMARY OF BOOSTER FLIGHT CHARACTERISTICS

FLIGHT PHASE		
SUBSONIC	99% OPTIMUM SPECIFIC RANGE NM/LB	
	ALL ENGS BEGIN CRUISE NO WIND	0.00388
	ALL ENGS END CRUISE NO WIND	0.00455
	ENG OUT BEGIN CRUISE WITH WIND	0.00273
	ENG OUT END CRUISE WITH WIND	0.00312
	OPTIMUM AVERAGE CRUISE ALTITUDE NO WIND (ALL ENGS), FT	18,000
	OPTIMUM AVERAGE CRUISE ALTITUDE WITH WIND (ENG OUT), FT	15,600
	OPTIMUM CRUISE MACH NUMBER	0.46
	CRUISE FUEL RESERVES, %	45.5
	CRUISEBACK RANGE, NM	457
	APPROACH SPEED, KTS	180
	APPROACH POWER SETTING, % MAX POWER LANDING WEIGHT, LB	550,469
	LANDING SPEED, KTS	180
	TOUCHDOWN ANGLE OF ATTACK, DEG	5
	COMPUTED DRY RUNWAY DISTANCE, FT	5,500
	FAA LANDING RUNWAY LENGTH (WET), FT	6,600
FERRY	TAKEOFF WEIGHT, LB	690,000
	TAKEOFF BALANCED FIELD LENGTH (FAA), FT	13,000
	CLIMBOUT RATE OF CLIMB (ALL ENGS, S.L.) FT/MIN	2,000
	CLIMBOUT RATE OF CLIMB (ENG OUT, S.L.) FT/MIN	1,600
	OPTIMUM SPECIFIC RANGE (ALL ENGS, AVE.) NO WIND NM/LB	0.00422
	OPTIMUM AVERAGE CRUISE ALTITUDE (ALL ENGS) NO WIND FT	18,000
	OPTIMUM AVERAGE CRUISE ALTITUDE (ENG OUT) WITH WIND FT	15,600
	MISSION RANGE (ALL ENGS), NM	500
	MISSION TIME (ALL ENGS), HR	1.75
	NOMINAL FUEL RESERVES, %	14

SHUTTLE BOOSTER REENTRY BASELINE TRAJECTORY 4.25 g – 55 DEG INCLINATION

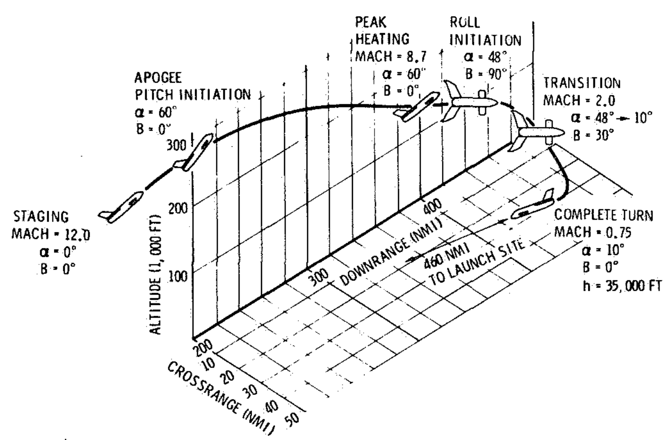


FIGURE 4-1

These, and the resultant MDAC Phase B Space Shuttle booster configuration (see Technical Summary, Booster, MDC E0308-II-3) will provide a datum for Phase C/D design development testing and testing to verify analytically predicted flight performance. Such testing envisions a configuration evolution toward total system design optimization with the following stages of development:

- Initial Baseline - The booster configuration at Phase C/D contractual authorization to proceed (ATP). Where practical, Phase B models will be modified, as necessary, and utilized for early Phase C tests. This will be evaluated as a means to provide early design information on a cost effective basis.
- Configuration Parametrics - Appropriate variations to the initial baseline configuration will be investigated to ascertain configuration changes required to improve the longitudinal and lateral-directional stability and control and performance characteristics, correct problem areas, and refine the configuration as necessary to satisfy Phase C contractual design safety and performance requirements.
- Requirements Baseline - The configuration resulting from integration of configuration parametrics evaluated during the previous stage of development. The resultant configuration would satisfy Phase C design safety and performance requirements.
- Optimized Baseline - A refinement to the requirements baseline supported by limited parametric tests directed toward overall design optimization. The configuration optimization would attempt to achieve the most efficient balance (and cost effectiveness) between optimum packaging, thermal design efficiency and optimum flight characteristics and handling qualities throughout the flight spectrum.
- Ferry Configuration - A design variation to the optimized baseline incorporating add-on propulsion and/or high lift modification kit necessary to achieve ferry mission performance requirements.

4.1 Wind Tunnel Testing - Wind tunnel tests of appropriately designed sub-scale models of the booster will be conducted to satisfy the requirements as stated in Section 4.1.2. The tests are categorized consistent with the data requirements to support aerodynamic, thermodynamic, loads, structural dynamic, and propulsion design analyses used in the booster configuration development and verification of predicted flight environment and performance. The tests are further categorized in accordance with the priority levels as presented in Figure 4.1-1.

TEST PRIORITY LEVELS

LEVEL	CRITERIA	MDAC INTERPRETATION
1	Program Critical. Related to crew safety, high probability of mission occurrence, very high confidence required of mission fulfillment.	Tests required to define and evaluate the Initial Baseline Configuration characteristics and to verify changes that bring the Initial Baseline Configuration to a state that meets the safety and performance requirements (Requirements Baseline Configuration).
2	Program Critical. Related to meeting overall objectives of Shuttle Program, high probability of mission occurrence, high confidence required of mission fulfillment.	Tests to characterize the Initial Baseline Configuration in off-nominal and short-time duration flight conditions.
3	Program Desirable. Related to crew safety-low probability of mission occurrence, high confidence required of mission fulfillment.	Tests to optimize the Requirements Baseline Configuration.
4	Program Desirable. Related to meeting overall objective of Shuttle Program, low probability of mission occurrence, low confidence required of mission fulfillment.	Verification/specialized testing of the Optimized Baseline Configuration that is expected to meet safety and performance requirements.
5	Insurance. Related to increasing Levels 1 through 4 to a higher confidence level of mission fulfillment.	Additional testing to more accurately define any of the above items (generally limited to #4).

FIGURE 4.1-1

The test priority level criteria, as shown in Figure 4.1-1 was defined by NASA-MSC LTR EX24/7101-15B, dated 20 January 1971. Since a literal interpretation of program criticality levels cannot be applied to wind tunnel tests on a one-to-one basis, an interpretation is presented which relates priority levels to evolution of configuration and associated wind tunnel tests. The priority system thus defined provides a systematic approach to the configuration development progressing from essential definition of a configuration to meet safety and performance requirements to an optimized configuration experimentally defined to a high confidence level. A logic diagram depicting the evolution of configuration (as defined in Section 4.) vs. aerodynamic wind tunnel tests by priority level is shown in Figure 4.1-2.

4.1.1 <u>Summary</u> - Approximately 28,200 occupancy hours of booster wind tunnel tests have been identified to satisfy the test requirements presented in Section 4.1.3. These hours delineated by technology category and priority level are summarized in Figure 4.1-3.

CONFIGURATION DEVELOPMENT LOGIC DIAGRAM
CONFIGURATION EVOLUTION VS. PRIORTIZED AERODYNAMIC TESTS

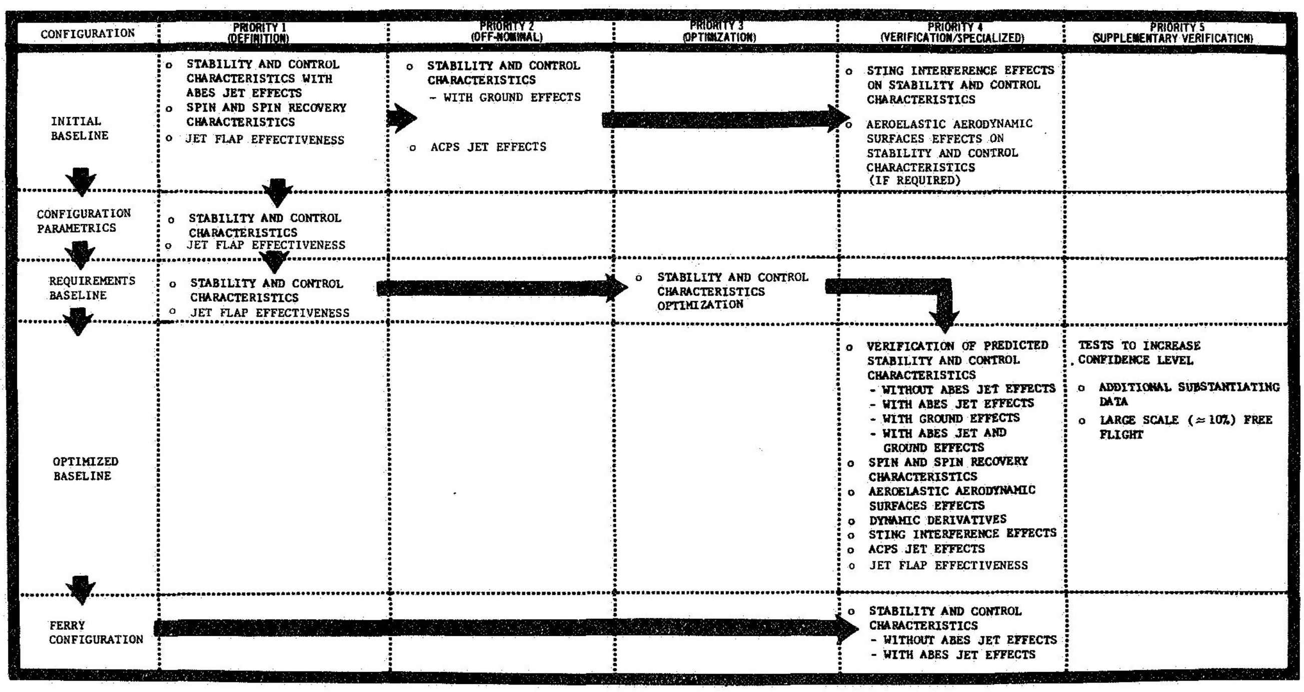


FIGURE 4.1-2

Summary of Booster Wind Tunnel Test
Occupancy Hours

CATEGORY \ PRIORITY	1	2	3	4	5	TOTALS
Aerodynamic	10,020	440	2,540	6,280	160	19,440
Thermodynamic	1,660	780	720	360	--	3,520
Loads	2,360	--	--	1,000	--	3,360
Struct. Dyn.	--	--	660	80	--	740
Propulsion	900	--	200	80	--	1,180
TOTALS	14,940	1,220	4,120	7,800	160	28,240

FIGURE 4.1-3

4.1.2 Requirements and Justification - Generalized wind tunnel data requirements by technology category are presented in Figure 6.1-4. These data are necessary to support design analyses encompassing configuration development and refinement and verification of predicted flight environment and performance.

4.1.3 Test Approaches - The proposed MDAC Phase C/D booster wind tunnel test program is presented in accordance with the technology categorization as follows:

4.1.3.1 Aerodynamic Wind Tunnel Tests

4.1.3.2 Thermodynamic Wind Tunnel Tests

4.1.3.3 Loads Wind Tunnel Tests

4.1.3.4 Structural Dynamic Wind Tunnel Tests

4.1.3.5 Propulsion (ABES) Wind Tunnel Tests

A listing of recommended facilities to accomplish the proposed tests is presented in Section 4.1.3.6. The schedule of performance of testing related to the major program milestones is presented in Section 4.1.3.7.

4.1.3.1 Aerodynamic Wind Tunnel Tests - The Phase C/D aerodynamic wind tunnel test program for the booster, summarized in Figure 4.1-5, provides the data necessary to fulfill the following objectives: (1) support design analyses, (2) configuration

BOOSTER WIND TUNNEL TEST DATA REQUIREMENTS

TEST DATA REQUIREMENTS	JUSTIFICATION
(a) Aerodynamics	
(1) The pitch-roll-yaw static and dynamic stability and control characteristics and associated flight performance throughout the entry, transition, cruise and landing flight modes, including conditions of subsonic spin.	Stability and control analyses and flight performance predictions.
(2) Induced aerodynamic forces and moments resulting from the operation of the ACPS and the ABES.	Stability and control analyses, ABES and ACPS design optimization, and flight performance predictions.
(b) Thermodynamics	
(1) Gasdynamic heating of the booster for conditions of entry, including assessment of heat transfer to the base region and main engine nozzles with and without main engines burning, heating of localized details such as windshield, leading edges, chines, fillets, and TPS protuberances and gaps.	Thermal environment definitions and TPS design.
(c) Loads	
(1) External pressure distribution of the booster during entry and post-entry, aerodynamic surface loads, and aerodynamic control surface hinge moments.	Structural analyses, TPS design, and local flow effects on performance and stability and control characteristics.
(d) Structural Dynamics	
(1) The fluctuating pressure environment and the aerodynamic surface dynamic loading resulting from buffet in the transonic regime and flutter boundaries for conditions of post-entry flight.	Structural dynamics analyses, TPS design, determination of dynamic environment, and prediction of flying qualities.

FIGURE 4.1-4

BOOSTER WIND TUNNEL TEST DATA REQUIREMENTS

TEST DATA REQUIREMENTS	JUSTIFICATION
(e) Propulsion	
(1) Airbreathing engines inlet duct pressure recovery, interaction with adjacent induction systems, and exhaust duct operating characteristics and interaction with adjacent engines and vehicle surfaces.	Airbreathing engine inlet and exit design, engine installation design, and operating envelope assessment.

FIGURE 4.1-4 (Cont.)

development, (3) evaluation of off-nominal and short-time flight conditions, (4) configuration refinement, and (5) verification of the final configuration that has been optimized consistent with safety and performance requirements. This test program assumes maximum advantage of the testing accomplished during and prior to Phase B but assumes that the Phase C/D contract will specify design changes necessitating new models for definition, evaluation, and optimization.

The proposed Space Shuttle booster aerodynamic wind tunnel occupancy hours for the Phase C/D test program are summarized by speed range and level of priority as defined in Figure 4.1-1. The test categories of (1) subsonic, (2) transonic, (3) supersonic, and (4) hypersonic speed regimes are representative of the complete spectrum of booster alone flight (beyond the influence of the orbiter flow field). The wind tunnel tests address the flight modes of post-separation (normal and abort), entry, transition, cruise and landing, and horizontal takeoff (ferry configuration). A major portion of the booster flight profile is depicted by the design entry trajectory shown in Figure 4-1 which is indicative of the magnitude and range of flight conditions requiring test simulation.

The subsonic and transonic Mach number ranges, comprising up to 99% of the flyback flight time, require the largest number of test hours to completely develop, optimize, and verify the orbiter configuration. The total test hours by priority

SUMMARY OF BOOSTER
AERODYNAMIC WIND TUNNEL TEST
OCCUPANCY HOURS

Priority Level	Speed Range: Subsonic	Transonic	Supersonic	Hypersonic	Totals
1	4,700	1,720	2,600	1,000	10,020
2	200	--	120	120	440
3	1,940	240	200	160	2,540
4	2,860	1,480	1,140	800	6,280
5	160	--	--	--	160
Totals	9,860	3,440	4,060	2,080	19,440

FIGURE 4.1-5

indicate that verification/specialized testing of the optimized baseline configuration (Priority 4) requires approximately 60% of the test hours needed to define and evaluate the initial baseline configuration characteristics with incorporated changes that may be required to meet safety and performance requirements (Priority 1).

A reasonable rate of expenditure of the required test hours based on the criteria of development of the configuration on a timely basis while allowing for reasonable time for analysis utilization of the test data, reasonable utilization of the test facilities, and timely support to the flight test program is shown by the schedule presented in Section 4.1.3.7. Percent of test completion by priority level with respect to major orbiter program milestones is presented in Figure 4.1-6.

An expanded summary of the booster aerodynamic wind tunnel test program is presented in Figure 4.1-7.

The subsonic tests listed provide data for determining the booster cruise, approach, landing, and ferry configuration longitudinal and lateral-directional static and dynamic stability and control characteristics, aeroelastic wing and vertical tail effects on stability and control, and spin and spin recovery char-

PERCENTAGE OF TEST COMPLETION
VS.
MAJOR PROGRAM MILESTONES

PRIORITY LEVEL	PROGRAM MILESTONES				
	PDR	CDR	2ND QUARTER 1975	PRIOR TO FIRST HTO*	PRIOR TO FIRST VTO*
Priority 1 (Definition)	60%	100%			
Priority 2 (Off-Nominal)	50%	75%	100%		
Priority 3 (Optimization)	40%	90%	100%		
Priority 4 (Verification/ Specialized)	5%	** 25%	75%	100%	
Priority 5 (Supplementary Verification)	10%	20%	50%	75%	100%

*HTO - Horizontal Takeoff
*VTO - Vertical Takeoff
** - Essential verification tests complete

FIGURE 4.1-6

acteristics. High angle of attack data for analytical spin studies are also included. The ABES jet effects on the cruise and landing configuration stability and control are also included. The transonic, supersonic, and hypersonic tests provide data for determining the booster entry, angle of attack transition, and cruise attitude static and dynamic stability and control characteristics, sting interference effects, and aeroelastic wing and vertical tail effects on stability and control (with thermal deformation effects included in the supersonic and hypersonic Mach number range). Also included are tests to determine Attitude Control Propulsion System (ACPS) jet-interaction effects in the supersonic and hypersonic Mach number range. Large scale model drop tests are included under the subsonic speed category for verification of both the spin tunnel experimental results and analytically determined spin and recovery characteristics. These drop tests could

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(1) AERODYNAMIC WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG. 4.1-16)	ESTIMATED OCCUPANCY HOURS
SUBSONIC	1. Longitudinal & Lateral Directional Stability & Control Characteristics	o Characterize the cruise & landing configurations & jet-flap canard configuration: - With & without ABES jet effects - With & without ground effects - Evaluate sting interference	Initial Baseline	1,2,3,4,5, 6,10,11	1340
		o Investigate appropriate changes to improve stability & control characteristics: - Wing development - Fuselage development - Vertical tail development - Control surface development - Jet-flap & canard development	Configuration Parametrics	1,2,3,4,5, 6,10,11	2360
		o Characterize & optimize the configuration resulting from the parameters investigation	Requirements Baseline	1,2,3,4,10, 11	2980
		o Verify stability & control & performance predictions - With & without ABES jet effects - With & without ground effects - Evaluate sting interference	Optimized Baseline	1,2,3,4,10, 11	2060
		o Investigate control effectiveness problems related to the ferry configuration	Ferry	1,2,3,4,10, 11	200
	2. Aeroelastic Effects	o Determine wing- and tail-surface aeroelastic effects on the longitudinal & lateral stability & control characteristics	Initial Baseline Optimized Baseline	1,2,4,5,10, 11 1,2,4,5,10, 11	200 100
	3. Dynamic Stability	o Determine the longitudinal & lateral directional dynamic stability characteristics	Optimized Baseline	1,4,7	300

FIGURE 4.1–7

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(1) AERODYNAMIC WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
SUBSONIC	4. Spin & Spin Recovery	o Determine the spin and spin recovery characteristics of the initial baseline configuration and verify predicted characteristics of the optimized baseline configuration using dynamically-scaled free-flight models.	Initial Baseline Optimized Baseline	8	240 80
	5. Large-Scale Free-Flight	o Determine the free-flight spin, spin recovery, and trim characteristics using dynamically scaled models dropped from a helicopter or aircraft.	Optimized Baseline	LRC, Edwds Flt. Test Center	N/A
				TOTAL	9860

FIGURE 4.1-7 (Cont.)

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(1) AERODYNAMIC WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
TRANSONIC	1. Longitudinal & Lateral Directional Stability & Control Characteristics	o Determine the transonic stability and control characteristics over a broad range of angle of attack (up to 60 degrees) - Evaluate sting interference	Initial Baseline	14,15,16, 18,19,20, 21,22,23, 24	380
		o Investigate appropriate changes to improve stability and control characteristics - Wing development - Fuselage development - Vertical tail development - Control surface development - Jet-flap canard development	Configuration Parametrics	13,15,23, 24	1180
		o Characterize and optimize the configuration resulting from the parametrics investigation	Requirements Baseline	14,15,18, 19,21,22, 24,23	440
		o Verify stability and control and performance predictions	Optimized Baseline	14,15,18, 19,21,22, 23,24	640
	2. Aeroelastic Effects	o Determine wing-and tail-surface aeroelastic effects on the longitudinal and lateral stability and control characteristics	Initial Baseline Optimized Baseline	14,15,16, 18,20,21	320 180
	3. Dynamic Stability	Determine the longitudinal and lateral directional dynamic stability characteristics	Optimized Baseline	13,14,15, 18,20,21, 22	300
				TOTAL	3440

FIGURE 4.1-7 (Cont.)

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(1) AERODYNAMIC WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
SUPERSONIC	1. Longitudinal and Lateral Directional Stability & Control Characteristics	o Determine the supersonic stability and control characteristics over a broad range of angle of attack (up to 60 degrees) – With and without ACPS effects	Initial Baseline	25,26,27, 28,29,31, 32,33,34	720
		o Investigate appropriate changes to improve stability and control characteristics	Configuration Parametrics	25,26,28, 30,32,33, 34	1500
		o Characterize and optimize the configuration resulting from the parametric investigation	Requirements Baseline	25,26,27, 28,29,30, 31,32,33, 34	700
		o Verify stability and control and performance predictions	Optimized Baseline	25,26,27, 28,29,31, 32,33,34	440
	2. Aeroelastic Effects	o Determine wing-and tail-surface aeroelastic effects on the longitudinal and lateral stability and control characteristics	Initial Baseline Optimized Baseline	25,26,27, 28,29,31, 32,33,34	260 140
	3. Dynamic Stability	o Determine the longitudinal and lateral directional dynamic stability characteristics	Optimized Baseline	27,28,31, 32	300
				TOTAL	4060

FIGURE 4.1–7 (Cont.)

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(1) AERODYNAMIC WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
HYPERSONIC	1. Longitudinal & Lateral Directional Stability & Control Characteristics	o Determine the hypersonic stability and control characteristics over a broad range of angle of attack (up to 60 degrees) - With & without ACPS effects	Initial Baseline	35,36,39, 40,41,43, 46,48,51, 52	380
		o Investigate appropriate changes to improve stability and control characteristics	Configuration Parametrics	35,37,40, 41,45,46	660
		o Characterize and optimize the configuration resulting from the parametric investigation	Requirements Baseline	35,36,39, 40,41,43, 46,48	280
		o Verify stability and control and performance predictions	Optimized Baseline	35,36,39, 40,41,43, 46,48	760
				TOTAL	2080

FIGURE 4.1-7 (Cont.)

be done at either the NASA Langley Research Center or the Flight Test Center at Edwards, California.

The recommended test facilities referenced in Figure 4.1-7 by numerical identification are presented in Section 4.1.3.6. A rationale for selection of the recommended facilities is given therein.

4.1.3.2 Thermodynamic Wind Tunnel Tests - The thermodynamic wind tunnel test program is required to supplement existing analytical methods for predicting aerodynamic heating, boundary-layer transition, and rocket exhaust effects on base heating. In addition, the test program will supply data to be used to establish the thermal integrity of the configuration.

Unlike the aerodynamic wind tunnel tests, the thermodynamic tests are limited to studies in the supersonic to hypersonic speed regime. Therefore, they have been categorized according to data gathering technique rather than speed regime. The test types are as follows:

Type 1 - Surface Flow Visualization - Oil-flow techniques will be utilized with scale models of the complete booster to identify streamline direction, vortex sheet impingement, boundary-layer separation and reattachment regions, and other local flow phenomena.

Type 2 - Thermal Mapping - Tests will be conducted with models having surfaces fabricated of low thermal diffusivity materials and coated with phase-change type paints. This technique provides contours of constant temperature (isotherms) and indicates high heating rate zones on the model.

Type 3 - Measurements at Discrete Locations - Models instrumented at discrete locations will be used to acquire quantitative data.

The hours of thermodynamic testing planned are summarized by test type and priority level in Figure 4.1-8.

Figure 4.1-9 is an expanded summary of the thermodynamic wind tunnel testing.

SUMMARY OF BOOSTER
THERMODYNAMIC WIND TUNNEL TEST
OCCUPANCY HOURS

TYPE OF TEST	PRIORITY				TOTALS
	1	2	3	4	
1. SURFACE FLOW VISUALIZATION	280	120	---	---	400
2. THERMAL MAPPING	400	120	200	---	720
3. HEAT TRANSFER	980	540	520	360	2,400
TOTALS	1,660	780	720	360	3,520

FIGURE 4.1–8

Each test will include, within the limitation of facility capability, conditions of Mach number and Reynolds number that simulate as nearly as possible the entry environment. A large portion of the planned testing will be conducted using small scale models of the complete booster vehicle. Many additional tests are planned where localized areas will be studied in great depth using large scale versions of particular components. Among these are the tests dealing with ACPS nozzle heating, jet-flap development, nose and forward fuselage configuration development, and the effects of surface protuberances and roughness.

Static pressure data will be gathered along with heat transfer data in Type 3 tests. In addition, one test will be devoted to pitot-pressure surveys of the boundary layer at various locations on the model to facilitate determination of the local flow conditions.

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(2) THERMODYNAMIC WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
SUPERSONIC	1. Surface Flow Visualization	o Identify areas possibly subject to high heating rates. Determine direction of streamlines near the vehicle surface. Locate shock-wave/boundary-layer interaction regions and boundary-layer separation/reattachment zones. - Base region, with and without booster plume effects - Base region, with one or more booster engines out - with ACPS effects	Initial Baseline Requirements Baseline	25,26,27 28,29,31, 32,33,34	160 40
	2. Thermal Mapping	o Use the phase-change paint technique to obtain thermal maps and further identify high heating rate regions	Initial Baseline Configuration Parametrics Requirements Baseline	31,32	210 50 100
	3. Heat Transfer Measurement	o Obtain quantitative heat transfer data in selected regions	Initial Baseline Requirements Baseline	28,29,31, 32,34	840 280
		o Verify thermal integrity of the optimized configuration	Optimized Baseline	28,29,31 32,34	200
				TOTAL	1880

FIGURE 4.1-9

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(2) THERMODYNAMIC WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
HYPERSONIC	1. Surface Flow Visualization	o Identify areas possibly subject to high heating rates. Determine direction of streamlines near the vehicle surface. Locate shock-wave/boundary-layer interaction regions and boundary-layer separation/reattachment zones - Base region, with and without booster plume effects - Base region, with one or more booster engines out - With ACPS effects	Initial Baseline Requirements Baseline	35,37,38, 39,40,41, 46,52	160 40
	2. Thermal Mapping	o Use the phase-change paint technique to obtain thermal maps and further identify high heating rate regions	Initial Baseline Configuration Parametrics Requirements Baseline	35,37,38, 39,40,41 46,52	210 50 100
	3. Heat Transfer Measurement	o Obtain quantitative heat transfer data in selected regions	Initial Baseline Requirements Baseline	35 through 52	680 240
		o Verify thermal integrity of the optimized configuration	Optimized Baseline	36,42,43, 44,47,48, 49,50,51	160
				TOTAL	1640

FIGURE 4.1-9 (Cont.)

4.1.3.3 Loads Wind Tunnel Tests - The proposed booster loads wind tunnel tests are categorized as follows:

a) Pressure Distribution Tests

b) Aerodynamic Surface Loads

c) Control Surface Hinge Moments

A summary of the proposed loads wind tunnel occupancy hours by these categories vs. speed range is presented in Figure 4.1-10.

BOOSTER LOADS WIND TUNNEL TESTS
OCCUPANCY HOUR SUMMARY

TYPE OF TEST	SPEED REGIME				TOTAL
	SUBSONIC	TRANSONIC	SUPERSONIC	HYPERSONIC	
PRESSURE DISTRIBUTION	620	420	380	200	1,620
AERODYNAMIC SURFACE LOADS	---	600	600	---	1,200
HINGE MOMENTS	---	300	240	---	540
TOTAL	620	1,320	1,220	200	3,360

FIGURE 4.1-10

The pressure distribution tests are required to provide supplementary experimental pressure data to accurately define distributed pressures on the vehicle. Initial tests are required early in Phase C/D in order that these data are available for input to the design load analysis cycle prior to PDR. Subsequent tests would be required to provide experimental pressure distribution data for the configuration design as it progresses in evolution from the Initial Baseline to a Requirements Baseline (by CDR) and verification of analytically predicted pressure distributions for the Optimized Baseline configuration. The aerodynamic surface loads tests and control surface hinge moment tests are required to provide aerodynamic loads and moments at the wing and vertical tail root sections and hinge moment data for the moveable control surfaces. Similar to the pressure distribution tests, tunnel entries would be required consistent with the need to provide design loads analysis for the Initial Baseline (by PDR) the Requirements Baseline (by CDR), and to verify analytically predicted design values for the Optimized Baseline configuration.

An expanded summary of the booster loads wind tunnel tests is presented in Figure 4.1-11.

4.1.3.4 Structural Dynamics Wind Tunnel Tests - The proposed booster configuration structural dynamics wind tunnel tests are categorized by the following types of tests:

a) Dynamic Loads Wind Tunnel Tests
   - o Post Entry Fluctuating Pressure
   - o Post Entry Buffet

b) Flutter Wind Tunnel Tests
   - o Complete Vehicle Flutter
   - o Panel Flutter

A summary of the proposed structural dynamic wind tunnel tests by types of test vs. speed range is presented in Figure 4.1-12.

Analytical techniques and methods alone are not sufficient to provide assurance that the dynamic characteristics and stability margins of the booster structure are accurately described. A structural dynamics wind tunnel test program combined with dynamic ground tests on models and full scale components and supplementary dynamic analyses will provide this assurance. The wind tunnel program has been established to obtain the data necessary to conduct dynamic response analyses, verify aerodynamic surface dynamic loadings, and determine stiffness requirements to prevent flutter of aerodynamic surfaces and external panels.

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(3) LOADS WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
SUBSONIC	1. Pressure Distribution	o Determine distributed or interference airloads on major components of the booster configuration.	Initial Baseline	1,2,4,10, 11	280
		o Provide pressures for external panel design and venting analyses.	Requirements Baseline		120
		o Verify analytical predictions of pressure distributions for the Optimized Baseline configuration.	Optimized Baseline	1,2,4,10, 11	120
				TOTAL	620

FIGURE 4.1–11

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(3) LOADS WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
TRANSONIC	1. Pressure Distribution	o Determine distributed airloads and shock interference on major components of the booster configuration.	Initial Baseline	13,14,15, 16,18,20, 21,22,23, 24	180
		o Provide pressures for external panel design and venting analyses.	Requirements Baseline		120
		o Verify analytical predictions of pressure distributions for the Optimized Baseline configuration.	Optimized Baseline	13,14,16,	120
	2. Aerodynamic Surface Loads	o Obtain booster aerodynamic surface loads and root bending moments using models with rigid and flexible surfaces.	Initial Baseline	13,14,16, 17,21	200
			Requirements Baseline		200
		o Verify analytical predictions of the aerodynamic surface loads and root bending moments for the Optimized Baseline configuration.	Optimized Baseline	13,14,16, 17,21	200
	3. Control Surface Hinge Moments	o Determine control surface loads and hinge moments for structural analyses and control power system design.	Initial Baseline	13,14,16, 17,21	120
			Requirements Baseline		120
		o Verify analytically predicted control surface hinge moments for the Optimized Baseline configuration.	Optimized Baseline	13,14,16, 17,21	60
				TOTAL	1,320

FIGURE 4.1-11 (Cont.)

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(3) LOADS WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
SUPERSONIC	1. Pressure Distribution	o Determine distributed airloads and shock interference on major components of the booster configuration	Initial Baseline	23,29,31, 32,33,34	100
		o Provide pressures for external panel design and venting analyses.	Requirements Baseline		100
		o Verify analytical predictions of pressure distributions for the Optimized Baseline configuration.	Optimized Baseline	28,29,31, 32,33,34	180
	2. Aerodynamic Surface Loads	o Obtain booster aerodynamic surface loads and root bending moments using models with rigid and flexible surfaces.	Initial Baseline	25,26,31	200
			Requirements Baseline		200
		o Verify analytical predictions of the aerodynamic surface loads and root bending moments for the Optimized Baseline Configuration.	Optimized Baseline	25,26,31	200
	3. Control Surface Hinge Moments	o Determine control surface loads and hinge moments for structural analyses and control power system design.	Initial Baseline Requirements Baseline	25,26,31	100
		o Verify analytically predicted control surface hinge moments for the Optimized Baseline configuration.	Optimized	25,26,31	40
				TOTAL	1,220

FIGURE 4.1-11 (Cont.)

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(3) LOADS WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
HYPERSONIC	1. Pressure Distribution	o Determine distributed airloads and shock interference on major components of the booster configuration.	Initial Baseline	35,36,40, 41,43,45, 46,47,49, 50	80
		o Provide pressures for external panel design and venting analyses	Requirements Baseline		40
		o Verify analytical predictions of pressure distributions for the Optimized Baseline configuration.	Optimized Baseline	35,36,40, 41,43,45 46,47,49,50	80
				TOTAL	200

FIGURE 4.1-11 (Cont.)

BOOSTER STRUCTURAL DYNAMIC
WIND TUNNEL TEST OCCUPANCY HOUR
SUMMARY

TYPE OF TEST	SPEED RANGE			
	SUBSONIC	TRANSONIC	SUPERSONIC	TOTAL
1. DYNAMIC LOADS	---			
o FLUCTUATING PRESSURE	---	80	80	160
o BUFFET	---	80	---	80
2. FLUTTER				
o VEHICLE	100	200	120	420
o PANEL	---	80	---	80
TOTAL	100	440	200	740

FIGURE 4.1-12

The supersonic and transonic regions of post entry flight are of primary interest. The only subsonic tests to be conducted will be for flutter. Both rigid and elastic models of maximum scale compatible with the test facility will be used. Ground vibration tests will be conducted on each elastic model to ensure that dynamic simulation is satisfactory.

An expanded summary of the booster structural dynamics wind tunnel tests is presented in Figure 4.1-13.

4.1.3.5 Propulsion (ABES) Wind Tunnel Tests - The proposed propulsion wind tunnel tests to be conducted on the booster configuration are categorized by the following types of tests:

a) Development Tests

b) Verification Tests

c) Functional Verification Tests

A summary of the proposed propulsion wind tunnel tests by types of test vs. speed range is presented in Figure 4.1-14.

The aims of the proposed tests are to optimize the ABES inlet for pressure recovery and minimize inlet distortion, to optimize the ABES exhaust nozzle and exit configuration to obtain optimum jet-flap efficiency, and to verify inlet

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(4) STRUCTURAL DYNAMIC WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
SUBSONIC	1. Flutter (Vehicle)	o Determine flutter boundaries for the booster during supersonic post entry flight using elastic model. o Determine design stiffness requirements for aerodynamic surfaces.	Requirements Baseline	1, 4, 11, 17	100
TRANSONIC	1. Dynamic Loads a) Fluctuating Pressure	o Determine fluctuating pressure environment acting on the booster during post entry flight in the transonic speed range. o Determine local pressures for panel design	Initial Baseline Requirements Baseline	13,14,18, 20,21	80
	1. Dynamic Loads b) Buffet	o Determine dynamic loads on the aerodynamic surfaces due to buffet in the transonic speed range. o Determine design stiffness requirements for aerodynamic surfaces.	Requirements Baseline	13,14,17	80
	2. Flutter (Vehicle)	o Determine flutter boundaries for the booster during transonic post entry flight using elastic model o Determine design stiffness requirements for aerodynamic surfaces	Requirements Baseline	4,14,12,21	200
	2. Flutter (Panel)	o Determine flutter boundaries for critical booster panels in the region of maximum dynamic pressure using dynamically scaled panels and edge support.	Requirements Baseline	4,14,17,21	80

FIGURE 4.1–13

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(4) STRUCTURAL DYNAMIC WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	FACILITY UTILIZATION (SEE FIG. 4.1-16)	ESTIMATED OCCUPANCY HOURS
SUPERSONIC	1. Dynamic Loads a. Fluctuating Pressure	o Determine fluctuating pressure environment acting on the booster during post entry flight in the supersonic speed range. o Determine local pressures for panel design	Initial Baseline Requirements Baseline	25,26,27, 28	80
	2. Flutter (Vehicle)	o Determine flutter boundaries for the for the orbiter during supersonic post entry flight using elastic model. o Determine design stiffness requirements for aerodynamic surfaces.	Requirements Baseline	25,26,29, 31	120
				TOTAL	740

FIGURE 4.1-13 (Cont.)

BOOSTER PROPULSION (ABES)
WIND TUNNEL TEST OCCUPANCY HOUR
SUMMARY

TYPE OF TEST	SPEED RANGE		TOTAL
	SUBSONIC	TRANSONIC	
1. DEVELOPMENT	120	440	560
2. VERIFICATION	40	120	160
3. FUNCTIONAL VERIFICATION	---	460	460
TOTAL	160	1,020	1,180

FIGURE 4.1-14

door performance at transonic speeds. The tests will be conducted on both large and small scale models of the booster and/or jet-flap canard panel.

The functional verification tests will be conducted on a full-scale engine in a large wind tunnel capable of providing proper freestream (altitude and speed) conditions. Start characteristics, engine-out effects, and fire extinguishing effectiveness will be investigated. An expanded summary of the booster ABES propulsion wind tunnel tests is presented in Figure 4.1-15.

4.1.3.6 Recommended Test Facilities - A list of wind tunnel facilities recommended for conduct of the proposed Space Shuttle Phase C/D booster wind tunnel tests is presented in Figure 4.1-16. These facilities, identified by consecutive listing number, are referenced to specific tests summarized within the foregoing technology categories. For each test or test type, a reference is given for several recommended facilities having capabilities which best match the particular test requirements. The facilities are listed by speed range (subsonic, transonic, supersonic, and hypersonic) and further categorized by controlling agency (NASA, Navy, Air Force, or Contractor). In addition to identifying the type of testing capability of the facility (force and moment, pressure, flutter, etc.) and Mach Number range, an approximate maximum booster model scale commensurate with the physical character-

WIND TUNNEL TEST PROGRAM SUMMARY
BOOSTER CONFIGURATION
(5) PROPULSION (ABES) WIND TUNNEL TESTS

CATEGORY	TYPE OF TEST	OBJECTIVE	APPLICABLE CONFIGURATION	RECOMMENDED FACILITIES (SEE FIG.4.1-16)	ESTIMATED OCCUPANCY HOURS
SUBSONIC	1. Development	o Optimize inlet, inlet door, and exhaust nozzle configuration (subscale models) - engine-out effects	Initial Baseline Requirements Baseline	2,3,6,7,10, 11	80 40
	2. Verification	o Verify initial design studies (large scale models) - engine-out effects	Requirements Baseline	2,3,6,7,10,	40
TRANSONIC	1. Development	o Optimize inlet, inlet door, and exhaust nozzle configuration (subscale models) - engine-out effects	Initial Baseline Requirements Baseline	14,16,19, 20,21,23, 24	360 80
	2. Verification	o Verify initial design studies (large scale models) - engine-out effects	Requirements Baseline	14,16,19, 20,21,23, 24	120
	3. Functional Verification	o Verify engine starting and engine-out effects - windmill start - cartridge start - cross bleed start - transient effects of flameout on adjacent engine - fire extinguishing agent distribution in engine compartment	Requirements Baseline Optimized Baseline	21	340 120
				TOTAL	1,180

FIGURE 4.1–15

WIND TUNNEL FACILITIES RECOMMENDED FOR PHASE C/D BOOSTER TESTING

NO.	FACILITY		CAPABILITIES	MAX. MODEL SCALE %	MACH NO.
			SUBSONIC		
			NASA		
1	Ames Research Center	12 Ft. Pt	F&M, P, DS, GW, GE, R_e	3.0	0 — .98
2	↓	7x10 Ft. SWT	F&M, P, JE	3.0	0 — .33
3		40x80 Ft. SWT	F&M, P, JE, GE, LSM	15.0	0 — .3
4	Langley Res. Center	7x10 Ft. HS	F&M, P, DS	3.0	.2 — .9
5	↓	7.5x3 Ft. LTPT	F&M, P, R_e	0.7	.1 — .4
6		V/STOL TRWT	F&M, P, JE, GE	3.0	0 — .3
7		30x60 Ft. FST	F&M, P, JE, DS, LMS	10.0	.03 — .14
8		Spin Tunnel	Free Flight Spin Testing	1.5	0 .08
9	Lewis Res. Center.	6x9 Ft. IRT	F&M	2.5	0 — .55
			NAVY		
10	Naval Ship Res. & Dev. Cen.	8x10 Ft. SWT	F&M, P, GE, JE, F	3.0	0 — .29
			CONTRACTOR		
11	McDonnell Douglas Corp.	8.5x12 Ft. LSWT	F&M, JE, GE, P, F	3.0	0 — .3
12	↓	Free Jet	Engine Exit Nozzle	3.0	——
			TRANSONIC		
			NASA		
13	Ames Research Center	14 Ft. TWT	F&M, P, DS	3.5	.6 — 1.2
14	↓	11 Ft. UPWT	F&M, P, DS, JE, R_e	2.0	.5 — 1.4
15		6 Ft. SWT	F&M, P, DS, R_e	1.0	.6 — 2.2
16	Langley Research Center	16 Ft. TT	F&M, P, JE	4.5	.5 — 1.3
17	↓	16 Ft. TDT	F&M, F	4.5	.5 — 1.2
18		8 Ft. PT	F&M, P, DS, R_e	1.5	.5 — 1.3
19	Lewis Research Center	8x6 Ft. SWT	F&M, P, DS, F, JE	1.5	.8 2.1
			NAVY		
20	Naval Ship Res.& Dev. Cen.	7x10 Ft. TWT	F&M, P, DS, F, JE, R_e	1.5	.4 — 1.2
			AIR FORCE		
21	Arnold Eng. Devel. Center	16T	F&M, P, DS, JE, F, HT, R_e	4.5	.5 — 1.6
22	↓	4T	F&M, P, DS, R_e	0.7	.5 — 1.3
			CONTRACTOR		
23	McDonnell Douglas Corp.	4 Ft. PSWT	F&M, P, JE, F, R_e	0.7	.5 — 5.8
24	↓	4 Ft. Trisonic	F&M, P, JE, HT, F, R_e	0.7	.2 — 5.0

DEFINITION OF TUNNEL CAPABILITIES:

F&M - Normal force and moment including hinge moments and panel forces and in most cases flow visualization.
P - Pressure distribution
DS - Dynamic stability
GW - Ground wind
GE - Ground effects
JE - Jet effects and propulsion airframe integration
R_e - High Reynolds number
LSM - Large scale models
F - Flutter, buffet
HT - Heat transfer

FIGURE 4.1–16

WIND TUNNEL FACILITIES RECOMMENDED FOR PHASE C/D BOOSTER TESTING

NO.	FACILITY		CAPABILITIES	MAX. MODEL SCALE %	MACH NO.
	SUPERSONIC				
	NASA				
25	Ames Research Center	9x7 Ft. UPWT	F&M, P, R_e, JE, F	1.5	1.5—2.6
26	↓	8x7 Ft. UPWT	F&M, P, R_e, JE, F	1.5	2.4—3.5
27	Langley Research Center	4 Ft. UPWT LEG1	F&M, P, DS, HT, JE, R_e, F	0.7	1.4—2.9
28	↓	4 Ft. UPWT LEG2	F&M, P, DS, HT, JE, R_e, F	0.7	2.3—4.6
29	Lewis Research Center	10x10 Ft. SWT	F&M, P, HT, JE, F	2.0	2.0—3.5
30	Marshall Space Flt. Cen.	14 In. TWT	F&M, P, HT, DS, R_e	3.0	.2—5.0
	AIR FORCE				
31	Arnold Eng. Devel. Cen.	16 S	F&M, P, DS, JE, F, HT	4.5	1.5—4.8
32	↓	Tunnel A	F&M, P, HT, DS, JE, F, Re	0.7	1.5—6.0
	CONTRACTOR				
33	McDonnell Douglas Corp.	4 Ft. PSWT	F&M, P, JE, F, R_e	0.7	.5—5.8
34	↓	4 Ft. Trisonic	F&M, P, JE, HT, F, R_e	0.7	.5—5.0
	HYPERSONIC				
	NASA				
35	Ames Research Center	3.5 Ft. HWT	F&M, P, HT, R_e	0.7	5, 7, 10, 14
36	Langley Research Center	4 Ft. HAT	F&M, P, HT	0.7	8—18
37	│	31 In. CFHT	F&M, P, HT	0.5	10, 11, 12
38	↓	18 In. VDHT	F&M, P, HT, R_e	0.35	8
39	Jet Propulsion Lab.	21 In. HWT	F&M, P, HT, DS, R_e	0.4	4—11.3
	AIR FORCE				
40	Arnold Eng. Devel. Cen.	Tunnel B	F&M, P, DS, JE, HT	0.7	6, 8
41	│	Tunnel C	F&M, P, DS, JE, HT	0.7	10, 12
42	↓	Tunnel F	F&M, P, DS, JE, HT, R_e	0.6	11—22
43	Aerospace Res. Lab.	30 In. HWT	F&M, P, HT	0.5	16—22
44	Airforce Flt. Dyn. Lab.	2 Ft. EGD	F&M, P, HT	0.4	6—12
45	↓	32 In. HTHWT	F&M, P, HT	0.5	8.5—11.5
	CONTRACTOR				
46	McDonnell Douglas Corp.	2 Ft. HWT	F&M, P, JE, HT, F, R_e	0.4	6, 8, 10
47	↓	30 In. HST	F&M, P, HT, R_e	0.5	7—20
48	Fluidyne Engr. Corp.	20 In. HWT	F&M, P, HT, DS, JE, R_e	0.4	7—18
49	Cornell Aero. Lab.	96 In. HST	F&M, P, HT, R_e	0.7	6.5—24
50	↓	48 In. HST	F&M, P, HT, R_e	0.7	5.5—20
51	LTV Aerospace Corp.	13 In. HWT	F&M, P, HT, DS, JE, R_e	0.25	12—20
52	Sandia Laboratories	18 In. HWT	F&M, P, HT, DS, R_e	0.35	5, 7, 9, 11

DEFINITION OF TUNNEL CAPABILITIES:

F&M - Normal force and moment including hinge moments and panel forces and in most cases flow visualization.
P - Pressure distribution
DS - Dynamic stability
GW - Ground wind
GE - Ground effects
JE - Jet effects and propulsion airframe integration
R_e - High Reynolds number
LSM - Large scale models
F - Flutter, buffet
HT - Heat transfer

FIGURE 4.1-16 (Cont.)

istics of the facility is given. An initial Phase C effort would be directed toward the selection of optimum model scales compatible with a wide range of recommended facilities and test conditions.

The recommended facilities, referenced to the foregoing tests, were selected according to the following guidelines:

(1) allow use of large models

(2) make maximum use of NASA-controlled facilities

(3) provide the test conditions which best allow the subscale simulation of the full-scale flight environment

(4) ability to support the test requirements of each particular test

(5) allow the conduct of several tests concurrently in different facilities to accomplish the tests in a time scale necessary to meet the program milestones.

(6) provide data of maximum reliability and accuracy to ensure the development of the configuration that most efficiently meets the safety and performance requirements with the lowest possible cost of test hours and dollars.

4.1.3.7 <u>Wind Tunnel Test Schedule</u> - The recommended schedule of performance of the proposed Phase C/D Space Shuttle booster wind tunnel tests is presented in Figure 4.1-17. Types of test, categorized by technology, are scheduled relative to major program milestones. Signficant aspects of the proposed schedule are:

- o Complete characterization of the Initial Baseline configuration and refinement of that configuration to a Requirements Baseline by CDR. Approximately 60% of this effort would be complete by PDR.
- o Effort toward design optimization of the Requirements Baseline 40% complete by PDR and 90% complete by CDR.

MASTER SCHEDULE

COORDINATION
ENG. ______
MFG. ______
PROC. ______
FLT. ______

PROGRAM: BOOSTER PHASE C/D WIND TUNNEL
CONTRACT: TEST PROGRAM SCHEDULE
REFERENCE: FIGURE 4.1-17

NO. E 0308-III-5-C
DATE ______
ISSUE E 0308-III-5-B
PAGE ______ OF ______

APPROVAL
PREP. BY Flickinger
APP. ______
APP. ______
APP. ______

	ACTIVITY	Schedule annotations
1	I. MAJOR PROGRAM MILESTONES	ATP; PDR; CDR; 1ST HTO; 1ST VTO; OC
2		
3	II. AERODYNAMIC WIND TUNNEL TEST	
4	oCHARACTERIZATION OF INITIAL BASELINE & REFINE-	(60); 10,020 HRS*
5	MENT TO REQUIREMENTS BASELINE (PRIORITY 1)	(50) (75)
6	oCHARACTERIZATION OF INITIAL BASELINE FOR OFF-	440 HRS*
7	NOMINAL SHORT DURATION COND. (PRIORITY 2)	(40) (90)
8	oOPTIMIZATION OF REQUIREMENTS BASELINE (PRIORITY	2,540 HRS*
9	3)	(5) (25) (75)
10	oVERIFICATION/SPECIALIZED TESTING OF OPTIMIZED	6,280 HRS*
11	BASELINE (PRIORITY 4)	(20) (50) (75)
12	oTESTING TO INCREASE CONFIDENCE LEVEL	160 HRS*
13	(PRIORITY 5)	
14		
15	III. THERMODYNAMIC WIND TUNNEL TESTS	DEVEL.; VERIF.
16	oSURFACE FLOW VISUALIZATION	400 HRS*
17		DEVEL.
18	oTHERMAL MAPPING	720*
19		DEVEL.; VERIF.
20	oHEAT TRANSFER MEASUREMENTS AT DISCRETE	2400 HRS*
21	LOCATIONS	
22	IV. LOADS WIND TUNNEL TESTS	DEVEL.; VERIF.
23	oPRESSURE DISTRIBUTION, AERODYNAMIC SURFACE	3360 HRS*
24	LOADS, & CONTROL SURFACE HINGE MOMENTS	
25		
26	V. STRUCTURAL DYNAMICS WIND TUNNEL TESTS	FLUCT. PRESS.; BUFFET, FLUTTER
27	oFLUCTUATING PRESSURE, BUFFET, VEHICLE AND	740 HRS*
28	PANEL FLUTTER	FLUCT. PRESS.
29		
30	VI. PROPULSION (ABES) WIND TUNNEL TESTS	
31	oENGINE INLET & EXIT NOZZLE DEVELOPMENT,	720 HRS*
32	ENGINE OFF EFFECTS	
33	oFULL SCALE INSTALLED ENGINE PERFORMANCE	460 HRS*
34		
35		

AFTER GO-AHEAD: 1–36 (months)
CALENDAR: 72, 73, 74, 75, 76, 77, 78, 79, 80

NOTES:
(XX) PERCENT COMPLETION
* TOTAL OCCUPANCY HRS PER LINE ITEM
** ESSENTIAL VERIFICATION TESTING COMPLETE

MAC 2220AB (1 APR 66)

MCDONNELL DOUGLAS

FIGURE 4.1-17

- o Essential testing to verify performance predictions relative to the Optimized Baseline complete by CDR. Testing related to the Priority Level 4 (Verification/Specialized testing of Optimized Baseline) continues beyond CDR, but primarily addresses testing which best fits the Priority Level 4 criteria per NASA/MSC Letter EX24/7101-15B (dated 20 January 1971), "Program Desirable Related to meeting overall objective of Shuttle Program, low probability of mission occurrence, low confidence required of mission fulfillment". Such tests include: spin and spin recovery characteristics, dynamic derivatives, aeroelastic aerodynamic surface effects on stability and control, sting interference effects, etc.
- o The majority of Thermodynamic, Loads, Structural Dynamics, and Propulsion wind tunnel development testing complete by PDR. Testing within these categories that are essential to the verification of predicted parameters critical to design will be completed by CDR. Testing beyond CDR is not expected to impact configuration design but is essential to the completion of performance analyses.
- o Wind tunnel tests to increase overall program confidence levels will probably be desired throughout the entire program. Such tests (Priority Level 5) are scheduled at a low level of effort to a point approximately 3 months prior to first vertical flight. It is envisioned that these tests would include supplementary testing to more accurately define or expand upon previous test results and provide data in support of the first horizontal and first vertical flight tests.

4.2 Flight Simulation

4.2.1 Description of Simulator - The basic parts of a functional man-in-the-loop simulator are the crew station, the visual simulation, the subsystem controls and displays, and the general purpose computer which is used to mechanize the simulator. A diagram illustrating the key elements of a man-in-the-loop simulator as required for the Booster is shown in Figure 4.2-1. The simulator as depicted is a functional simulator, i.e., math models are used to simulate the system rather than this function being performed by actual equipment, except for the cockpit controls and displays.

KEY ELEMENTS OF A MAN-IN-THE-LOOP SIMULATION

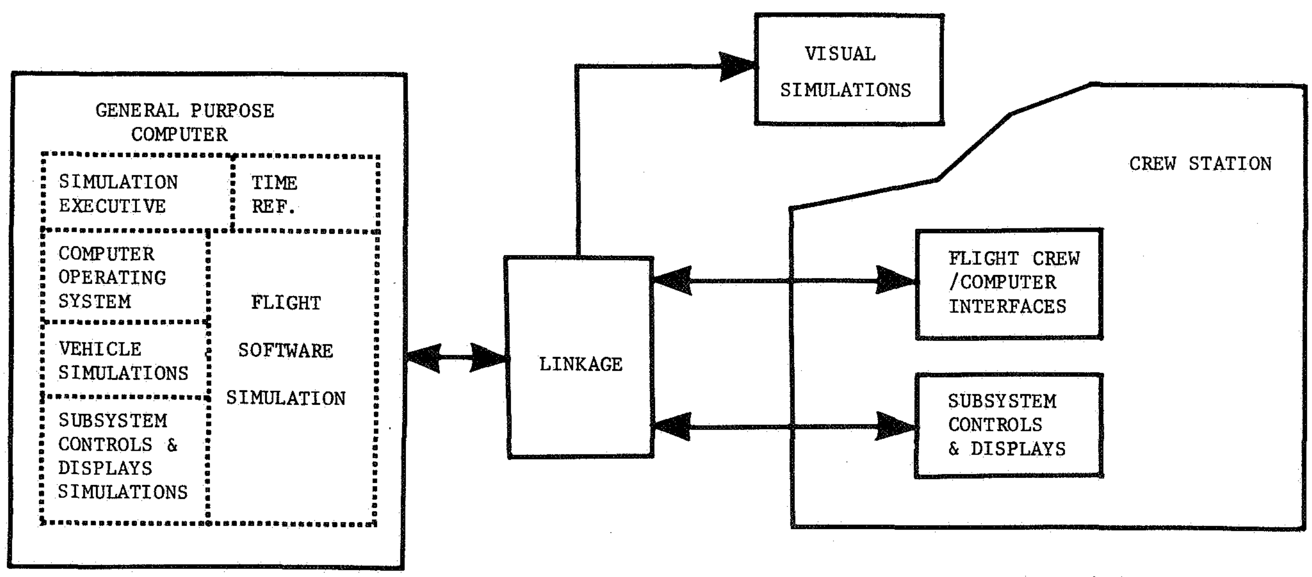


FIGURE 4.2-1

The simulator in total is made up of numerous separate simulations that are combined in a manner to provide realism. The most obvious part of the simulator is the cockpit which is a replica of the interior of the actual crew station. Visual simulations for animated window displays are mounted onto the simulated crew station. The visual simulations usually involve several closed circuit TV systems with servoed cameras and models for required all-attitude geometry. A system of lens and mirrors are frequently used to enhance the fidelity of the video images seen by the observer in the cockpit. Because of the digital flight computer, a flight crew/computer interface is required. This interface is normally a keyboard for inserting data into the flight computer and a display for flight computer read-out. On Apollo this was the Display Keyboard (DSKY). On the booster, there will be a number of Cathode Ray Tubes (CRT's), each with a corresponding keyboard which the flight crews will use to control the various computer operations and modes. Also mounted in the cockpit are all the various instruments, levers, switches, panels and displays that make up the subsystem control and display simulations. Engine RPM, altimeters, VOR/DME, flight directors and throttles are typical devices which are mechanized subsystem control and display simulations.

The next component of the simulator concept shown in Figure 4.2-1 is the linkage of the cockpit with general purpose computer. Primarily, the linkage is A/D and D/A signal conversions. The general purpose computer provides the simulation program which functionally simulates the basic airplane and all its subsystems. The flight computer software is also simulated functionally on the general purpose computer. When the flight computer becomes available, it can be interfaced to operate with the general purpose computer. The programming of the general purpose computer usually incorporates most of the elements illustrated by Figure 4.2-1. The time reference in the general purpose computer is used to synchronize the computer outputs with real-time time. The simulator executive schedules the computations and input/output operations required for the simulation to perform correctly. The operating system, provided by the computer vendor, interfaces the simulation programs with the computer. The vehicle simulations are the equations of motion, the geometry for mechanizing the visual simulations and the equations for parameters to be measured by the sensors (e.g., altitude, attitude, airspeed, and range). The subsystem controls and displays simulations are functional (logic and math) models of each system. Flight controls, throttles, thrusters, flaps, tracking devices, and platforms typify the various flight systems. The flight software simulation, which is the largest part of the simulator program, is normally only partially done depending upon the objectives of the simulator involved and of the test objectives. Because of this, and the possibility of other simulators required by the NASA for the Space Shuttle program, coordination of the flight software simulations with the NASA and other prime vehicle contractors will be necessary.

4.2.2 Requirements - Man-in-the-loop simulations will be required throughout the booster-orbiter development program. Initially, simulations will be required to determine preferred methods of operations from the standpoint of the flight crew. The simulations will then be used to identify the requirements of the flight crew interface which will be reflected into the designs and specifications of the flight hardware and flight software. Simulations will then be required to evaluate the designs and whether they have placed constraints on the preferred methods of operation. The man-in-the-loop simualtions will be updated and improved during the Shuttle development phase and can be used to perform flight crew training tasks later in the Shuttle program.

The tasks requiring mechanized cockpit simulators to do man-in-the-loop evaluations on the Shuttle program are as follows:

(a) Establish preferred methods of nominal and abort operations throughout the mission and conduct pilot rating of the flight controls.

(b) Perform frequent demonstrations of the preferred methods of operations and evaluate any constraints imposed by variations in the flight system design.

(c) Support test facilities with tailored simulations of the flight systems and flight conditions.

(d) Design and develop flight software simulations and document the necessary specifications, descriptions, and integrated verification data.

(e) Develop detailed flight crew procedures for nominal time critical phases of the missions and also for the abort modes.

(f) Provide flight crew proficiency training and flight plan verification.

Task (a) is required jointly by NASA and MDAC. Tasks (b), (c), and (d) are required by MDAC. Tasks (e) and (f) are performed traditionally by the NASA at their facility.

On the Booster program, there are two recognized areas where mechanized cockpit simulators are applicable due to different requirements.

- o System design and development at MDAC
- o System operations and training at NASA

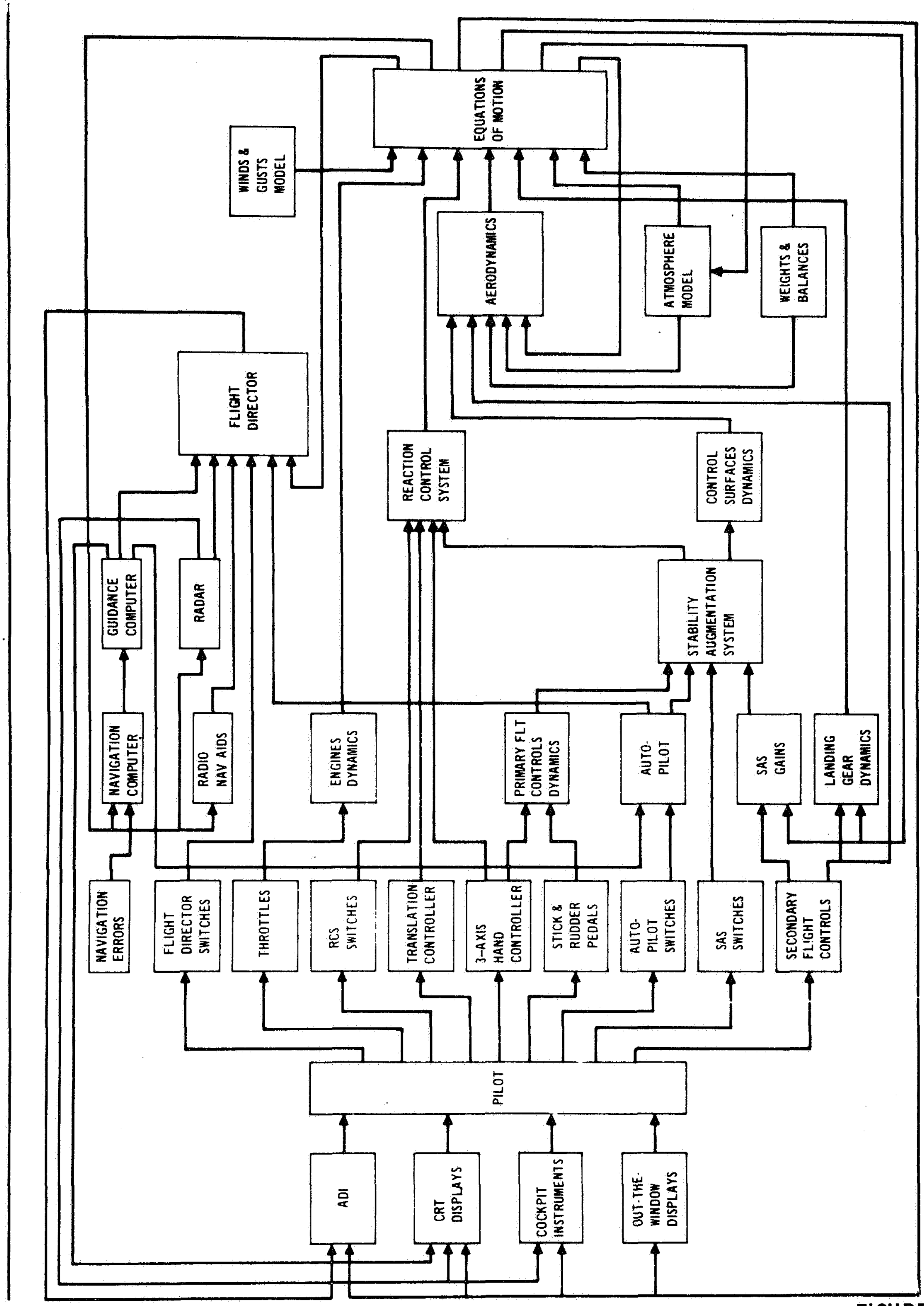
The simulation activities in these two areas reflect clear divisions of facilities, disciplines, objectives and timing requirements. In the first area, MDAC's simulation facilities, resources and development requirements are dedicated to developing flight system hardware. Because of this, primary interest will be on evaluations of design parameters and performance data. On the other hand, NASA's simulation facilities are oriented toward establishing preferred methods of operation and dedicated crew training.

An engineering cockpit simulator is required at MDAC to satisfy the requirements delineated above. Because of the increased scope of the digital flight computer functions, there is also a requirement for a flight software simulator which can be used in performing the tasks of flight software specification, flight software development and flight software integration verification. These aspects of software testing are addressed in Paragraphs 5.3.7 and 6.2.

4.2.3 Approach - McDonnell Douglas (MDAC) will utilize an improved version of a fixed-based, six degree of freedom flight simulator which was used for the Phase B simulation activities. The fixed-base cockpit simulator will be modified to have functional simulations of flight computer programs, CRT displays, and keyboards. Functional simulations will provide two-man operation, subsystem management, and GNC operations pertinent to evaluating the preferred methods of operation. CRT displays will be designed and mechanized. Man-in-the-loop simulations forcing integration of subsystem management and GNC aspects of crew functions will be conducted to test maturity of design philosophy and crew/computer procedures. The simulator will be used to coordinate preferred methods of operation with NASA and pertinent subcontractors. The Shuttle Simulator facility currently includes a crew station, instrumentation and displays, a landing site terrain model, and a rendezvous target model. In pursuit of Phase B objectives, configurations, control systems (including artificial stabilization), and navigation aids were programmed and are operational. A functional flow diagram of the Shuttle simulation program is provided in Figure 4.2-2.

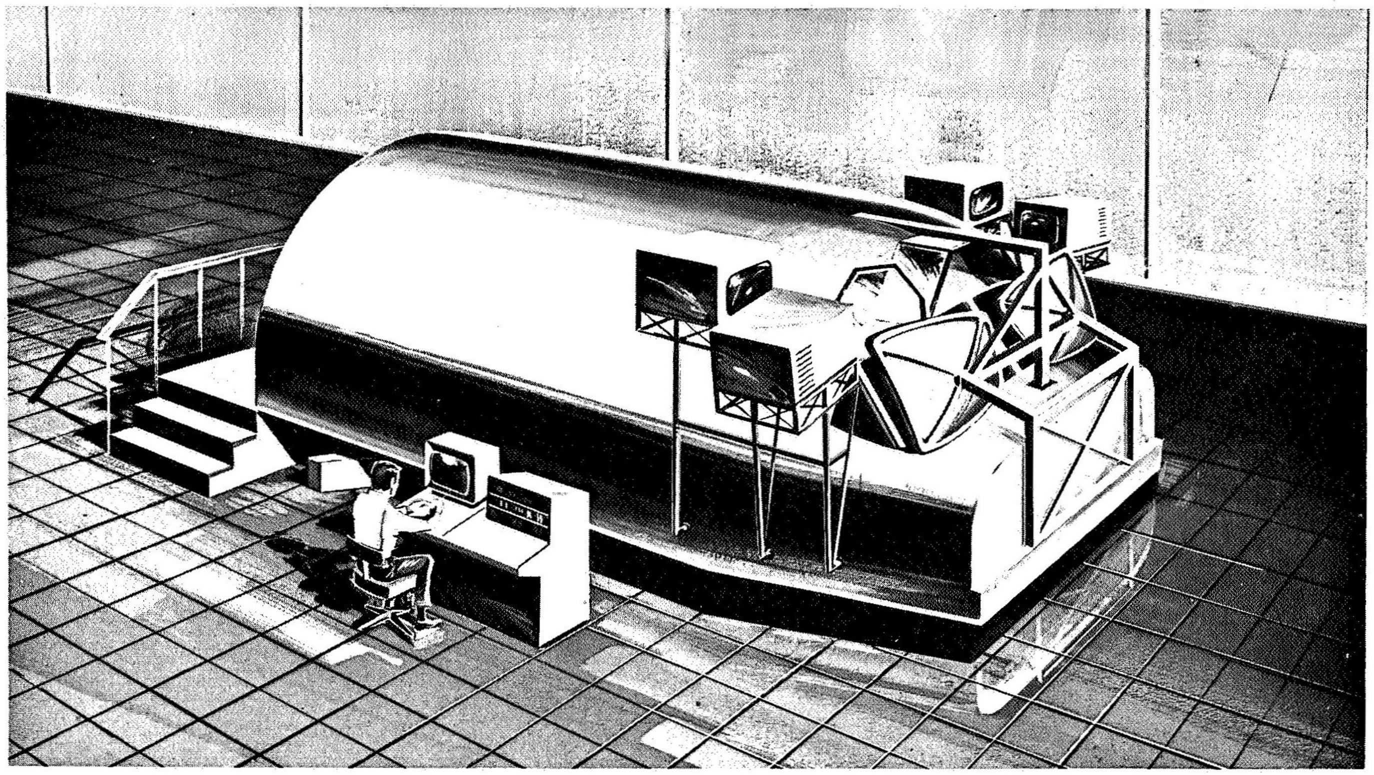
The fidelity of the Shuttle simulator is currently being improved with respect to cockpit and window visual displays. This High Fidelity Shuttle Simulator (HFSS) will be equipped with the controls and displays listed in Figure 4.2-3 by the end of 1971.

A coordinated master plan of the simulators and hardware/software simulations which are pertinent to the booster program will be prepared. Particular attention will be directed to optimizing combinations of such mission phases as Boost, Boost Abort, Rendezvous, Entry-Transition and Approach-Landing-Roll-out with identifiable simulators such as software simulators, procedures simulators, moving base trainers, and mission simulators. As the functions to be performed are determined, the operational parameters for the computer will be enumerated to determine overall requiements such as total number of instructions, computational rates and memory capacity.



SPACE SHUTTLE SIMULATION PROGRAM

FIGURE 4.2-2



CONTROL STICK	CAUTION AND WARNING LIGHTS
RUDDER PEDALS	VOR/DME & ILS SELECT
THROTTLES	NAVIGATION SENSORS
ATTITUDE HAND CONTROLLERS	COMPUTER KEYBOARD
TRANSLATION CONTROLLERS	ORBIT ATTITUDE CONTROL PANEL
NOSE WHEEL STEERING	TRANSLATION CONTROL PANEL
LANDING GEAR	CRT (GRAPHICS) DISPLAYS
FLAPS	ELASPED TIME
ABORT	GMT
ADI	EVENT TIMERS
ALTIMETER	NAVIGATION POSITION
RADAR ALTIMETER	DME DISPLAY
MACH/AIRSPEED	RANGE RATE
ANGLE OF ATTACK	AUTO CHECK LIST
ACCELEROMETER	VENT CONTROLS
RATE OF CLIMP	LIGHTING AND SEAT CONTROLS
HSI	VOR/DME & ILS FREQUENCY DISPLAY
	VOR/DME & ILS FREQUENCY SELECT

HIGH FIDELITY SHUTTLE SIMULATOR

FIGURE 4.2–3

In addition to defining common simulator software which includes the equations of motion, MDAC will also determine the incremental requirements for the Space Shuttle avionics simulation separately for each simulator and will describe the fidelity and commonality of each avionics simulation in detail. MDAC will prepare supporting rationale for the particular design philosophy underlying the selections which include as a minimum, a description of predicted flight crew operations over an entire mission as they are pertinent to functions such as rendezvous and entry guidance, navigation, attitude control, checkout, fault isolation, data management, onboard mission/flight planning.

MDAC will conduct an examination of each simulation individually to identify requirements which are pivotal to the successful development of the avionics for that simulation. Special attention will be focused on the structure of the simulator software, the design of the simulator executive, the requirements for simulating the highly redundant data bus and the feasibility of interchanging functional simulations with actual avionics components on the data bus. Simplified working models of the simulations will be devised to demonstrate feasibility and to provide design data on the techniques, especially in those areas where more than one technique and/or simulation element is acting concurrently, e.g., multiplexed CRT displays, sensor data displays, fly-by-wire controls, equations of motion, and cockpit motion during a landing approach.

MDAC will describe the techniques for developing the avionics simulations and will provide the necessary guidelines and conditions for proper use. MDAC will identify all components of the computer equipment and programming languages which are required and possible alternate schemes.

MDAC will provide the computational requirements for each simulation as a basis for specifying the configuration of the computer facilities which mechanize the Space Shuttle simulations. Candidate configurations, including the operating system characteristics, will be examined relative to the number and types of computers, iteration speed, memory capacity, mass storage devices, data access speed and techniques, periphery equipment, hybrid interfaces and other unique functions of the simulations.

On the Gemini and Apollo programs, it was soon learned that fixed based simulators with high fidelity visual simulations were more suitable for spacecraft simulations. On the other hand, commercial aviation has shown a trend toward moving base simulators for training. Inability to remove the effects of gravity and the utilization of visual measurements have led the way toward fixed base design of spacecraft simulators while the importance of cues derived from apparent acceleration and airplane motion during off nominal situations have led to moving base simulations for the airplane simulators. Since the Space Shuttle combines both modes of flight, the simulators can be divided into two groups accordingly, fixed base and moving base. Because of the training and mission operations, any moving base simulations should be performed at the NASA facilities. The MDAC schedule for the Booster man-in-the-loop simulations is presented in Figure 4.2-4.

4.2.4 Support - The McDonnell Douglas Flight Simulation Facility will be used to support the mechanization of the Shuttle simulations at MDAC. Similar simulation facilities are recommended for flight simulator support at NASA. The McDonnell Douglas Flight Simulation Facility is a unified laboratory complex, which is comprised of crew station mock-ups with operational controls and instrument, closed circuit television out-the-window displays, a large hybrid computer system and the software required to accurately define a system and integrate the hardware elements.

Flexibility has been achieved through a centrally located computer complex with peripherally located crew stations and display equipment. This arrangement permits any of the display scenes to be "patched in" to any of the crew stations. The facility is capable of operating two hybrid simulations and several analog

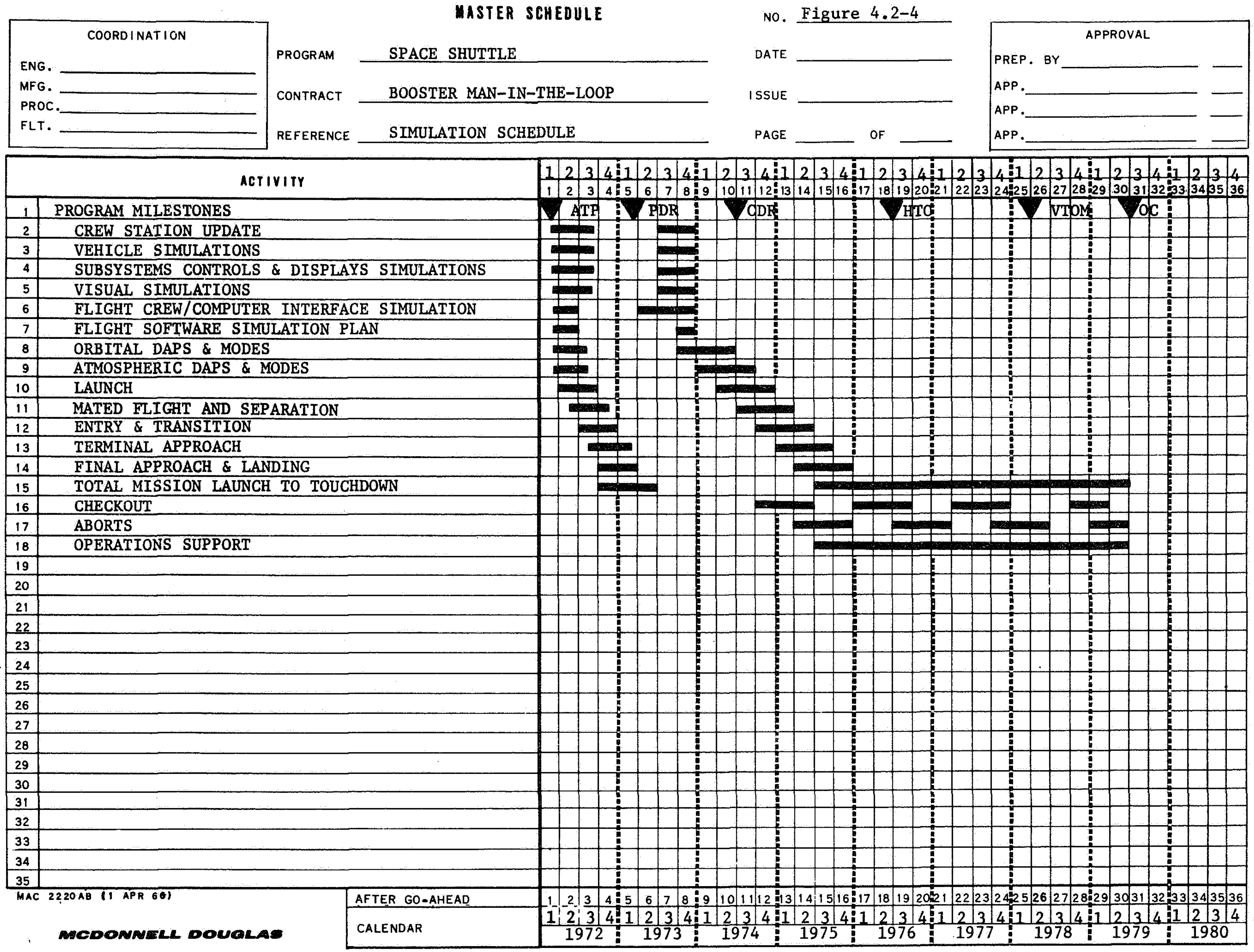

MASTER SCHEDULE
NO. Figure 4.2-4
COORDINATION
ENG.
MFG.
PROC.
FLT.
PROGRAM SPACE SHUTTLE
CONTRACT BOOSTER MAN-IN-THE-LOOP
REFERENCE SIMULATION SCHEDULE
DATE
ISSUE
PAGE OF
APPROVAL
PREP. BY
APP.
APP.
APP.
ACTIVITY
1 PROGRAM MILESTONES
2 CREW STATION UPDATE
3 VEHICLE SIMULATIONS
4 SUBSYSTEMS CONTROLS & DISPLAYS SIMULATIONS
5 VISUAL SIMULATIONS
6 FLIGHT CREW/COMPUTER INTERFACE SIMULATION
7 FLIGHT SOFTWARE SIMULATION PLAN
8 ORBITAL DAPS & MODES
9 ATMOSPHERIC DAPS & MODES
10 LAUNCH
11 MATED FLIGHT AND SEPARATION
12 ENTRY & TRANSITION
13 TERMINAL APPROACH
14 FINAL APPROACH & LANDING
15 TOTAL MISSION LAUNCH TO TOUCHDOWN
16 CHECKOUT
17 ABORTS
18 OPERATIONS SUPPORT
ATP
PDR
CDR
HTC
VTOM
OC
AFTER GO-AHEAD
CALENDAR
1972
1973
1974
1975
1976
1977
1978
1979
1980
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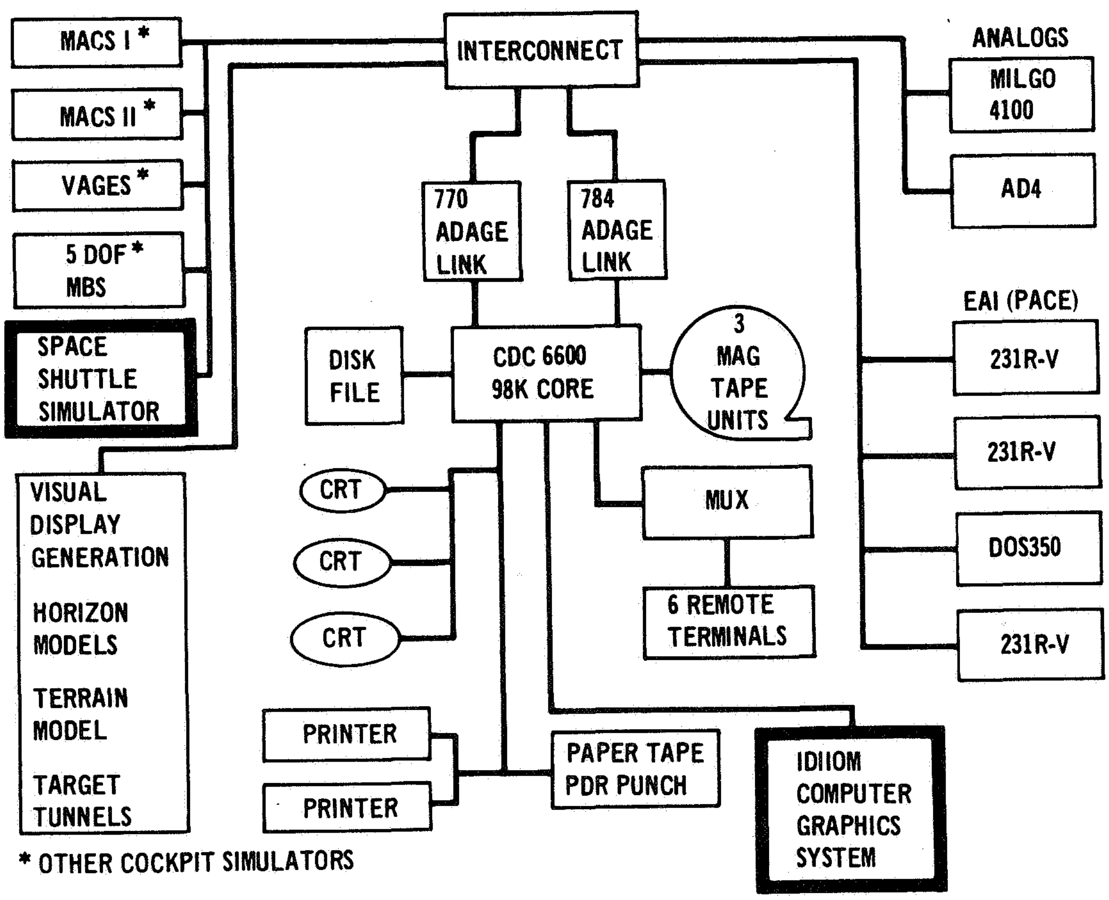
FIGURE 4.2-4

simulations simultaneously (e.g., mated booster and orbiter through separation and resulting trajectories).

The hybrid computer system is comprised of two digital computers with peripheral equipment, an Information Displays, Inc. Computer Graphics System (IDIIOM), two linkage systems for analog to digital and digital to analog conversions and a number of different types of analog computers. Figure 4.2-5 shows the manner in which the hybrid facilities are interfaced. A Control Data Corporation (CDC) 6600 digital computer is the primary unit in the hybrid system. A VARIAN 620i is used as a satellite computer to the 6600 for driving CRT displays.

SIMULATION SYSTEM INTERCONNECT



* OTHER COCKPIT SIMULATORS

FIGURE 4.2-5

The CDC 6600 is a large, general purpose, multiprocessor, multiprogrammed digital computer capable of servicing two or more independent hybrid problems simultaneously. The 6600 can also control and setup the analog computers and provide alphanumeric CRT displays to operators and programmers. It has a central processor with 60 bit word, 98k memory, 10 peripheral processors with 12 bit word and 4k each of memory and major and minor cycles of 1 microsecond and 100 nanoseconds, respectively. Other features include:

12 12-bit I/O channels (2 megacycle character transfer rate)

2 Line printers

1 Card reader

1 Dual CRT console

3 Magnetic tape units (200, 556, 800 BPI)

6 Remote CRT consoles

1 Disk file with 75,000,000 character capacity

2 Remote terminal multiplexers

The VARIAN 620i has a 16 bit word (plus memory parity), 12K memory with a 1.8 microsecond cycle time. It uses fixed point arithmetic and eight external interrupts. Other features include:

1 Fully buffered data channel

1 10 character/sec. paper tape station

1 Magnetic tape unit (556 and 800 BPI)

1 6600 to 620i channel coupler

The IDIIOM is a display and information input-output system with a programmable memory. It enables the user to work directly with a wide range of stored information and data processing operations. IDIIOM can be used alone, or for large scale manipulations such as the Space Shuttle D&C Simulations, it functions as an output terminal for the CDC 6600. IDIIOM will produce up to six separate CRT displays for cockpit use. The principal components of the system are given below.

3 21 inch CRT display screens

1 Interactive light pen

1 Function keyboard (32 keys)

1 Alphanumeric keyboard and printer

Two analog to digital, digital to analog converter systems are available, an Adage 770 and an Adage 784.

4.3 In-Flight Verification - The flight test verification of the booster mission or flight characteristics occurs as an integral part of the vertical flight test (Section A Paragraph 7.5) and horizontal flight test (Section B Paragraph 7.4) programs.

4.3.1 Flight Characteristics Test Requirements - The flight characteristic test requirements are contained in the System Flight Test Requirements (Section A Paragraph 7.5, Figure 7.5-1) and the Booster HTO Flight Test Requirements (Section B Paragraph 7.4, Figure 7.4-1). They are excerpted from these tables and listed here as Figures 4.3-1 and 4.3-2 for convenience.

BOOSTER HTO FLIGHT TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
o o o	
(IV) Test Vehicles - Flight development and verification testing in the horizontal takeoff regime shall be constrained to the first three boosters constructed. Modifications to test vehicles to perform development and verification flights shall be so designed, fabricated, and installed that ready conversion and refurbishment can be made to the operational configuration following flight tests. Specific modifications to the test vehicles for HTO flight tests will be designed, fabricated, and installed by the booster contractor. These shall consist of the following:	Cost considerations.
o o o	

FIGURE 4.3-1

BOOSTER HTO FLIGHT TEST REQUIREMENTS
(CONTINUED)

TEST REQUIREMENTS	JUSTIFICATION
o o o	
(2) Antispin Device - Until the transition handling characteristics of the booster have been determined, no flights in the transition regime shall be made without an approved antispin device installed ready for use. The antispin device shall be designed to fit within the normal contour of the vehicle and so that the possibility of fouling controls before or after operation is reduced to a minimum. The functional operation of the device will be demonstrated prior to commencing vertical testing.	This is a vehicle safety consideration.
(V) Specific Requirements (booster HTO tests) -	
o o o	
(b) Minimum Requirements - Preferry Shakedown	
(1) Subject vehicle and subsystems to a minimum of three hours flight time.	This is a time and cost consideration and is aimed at eliminating need for maintenance and repairs at off-site locations during ferry.
(2) Evaluate flying qualities and performance of booster under limited flight conditions for ferry under VFR/escort conditions.	

FIGURE 4.3-1 (Cont.)

BOOSTER HTO FLIGHT TEST REQUIREMENTS
(CONTINUED)

TEST REQUIREMENTS	JUSTIFICATION
(c) <u>HTO Test Requirements Which Must Be Completed Prior to VTO Tests</u> -	
(1) Demonstrate safe and acceptable flying qualities throughout the nominal altitude-speed envelope required to return to the launch site from transition.	These minimum requirements are defined to provide a level-of-confidence for initial VTO flight recovery operations under ideal return conditions.
o o o	
(4) Assess the booster vehicle's airbreathing cruise performance sufficiently to verify design mission profiles for cruiseback and landing.	
(5) Assess the booster vehicle's landing approach and landing performance and characteristics to verify and refine operational procedures and techniques.	
o o o	
(7) Demonstrate satisfactory operation of any other subsystem required for operation in the cruiseback and landing flight regime.	
o o o	

FIGURE 4.3-1 (Cont.)

BOOSTER HTO FLIGHT TEST REQUIREMENTS
(CONTINUED)

TEST REQUIREMENTS	JUSTIFICATION
(d) Minimum Requirements Prior to Operational Capability –	
(1) Demonstrate safe and acceptable flying qualities throughout the required operating envelope for the ferry configuration.	Most economical method of proving system.
o o o	
(4) Verify flight profiles for ferry.	
(5) Verify acceptable take-off and landing performance.	
o o o	
(7) Verify satisfactory operation of all other subsystems utilized in ferry flight mode.	
o o o	

FIGURE 4.3–1 (Cont.)

SYSTEM FLIGHT TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATIONS
o o o	
<u>Minimum Requirements (Vertical Takeoff Tests)</u>	
(1) Verification of the Space Shuttle System in the ascent phase from prelaunch through separation from zero to maximum payload capability.	Final verification for operational status will require flight demonstration.
(2) Verification of the booster entry and cruiseback and landing phase.	
o o o	

FIGURE 4.3–2

4.3.2 <u>Flight Characteristics Test Approaches</u> – The approach to the inflight verification of the booster flight characteristics is divided into horizontal takeoff and vertical takeoff sections.

4.3.2.1 <u>Horizontal Flight Characteristics Verification Approach</u> – The booster characteristics associated with the cruiseback and landing and the ferry flight phases will be evaluated and verified during the horizontal flight test program. The overall horizontal flight test approach is described in Paragraph 7.4.2. The minimum flight test hours required to satisfy the flight characteristics test requirement are tabulated in Section 7.4.2.3 Figure 7.4–6 and their planned distribution by test vehicle and site are shown in Figures 7.4–9 and 7.4–10 of that section.

Preliminary Evaluation (Figure 4.3-1 Test Requirement Nos. (V)b and (V)c) - The evaluation conducted at KSC will constitute that part of the horizontal test program required prior to the first, and minor, program milestone--ferrying the airplane to the prime horizontal test site. Vehicle flight handling qualities and performance during takeoff, landing, and cruise flight will be evaluated and the absence of unsafe flight characteristics will be verified. The preliminary flight evaluation will be completed following arrival at Edwards AFB. The cursory investigation of the vehicle flight envelope will be completed. The general overall handling qualities, stability and control, performance, and subsystem operation will be evaluated to verify the absence of major deficiencies in basic airplane flight characteristics.

Stability and Control (Figure 4.3-1 Test Requirement Nos. (V)c1 and (V)d1) - Booster airplane stability and control characteristics - longitudinal, lateral, and directional - will be evaluated and verified throughout the airplane flight envelope. Exploration of the flight envelope will be done in a build-up fashion proceeding incrementally from the minimum flight conditions to the extremes of the envelope. Vehicle handling qualities, static and dynamic stability, control forces and power, trim characterisics, and maneuvering capabilities will be evaluated in level flight acceleration and deceleration, stick raps, rudder kicks, rolls, and wind-up turns. The effects of gross weight, center of gravity position, and booster configuration--landing gear position, airbreathing engine power settings, jet flap position, or extension of other appurtenances will be evaluated as applicable. The absence of adverse effects from landing gear extension/retraction transients will be verified. Handling qualities and control characteristics during approach and landing, takeoff, and in unusual flight attitudes and turbulence will be verified to be satisfactory. Airbreathing engine-out handling qualities, control characteristics, and minimum control speeds will be determined.

This testing will be conducted in the basic manual fly-by-wire control system mode and interfaces with the Avionic subsystem flight control testing. The evaluation, over a reduced number of flight conditions, will be repeated to verify the handling characteristics of redundant branches of the stability augmentation system.

Stability and control testing, as well as performance and stall characteristics testing, must be scheduled so that the verification of that part of the booster flight envelope and conditions which encompass the posttransition subsonic glide, cruise, approach and landing will be completed prior to the first manned orbital mission.

Performance (Figure 4.3-1 Test Requirements Nos. (V)c4 & c5 and (V)d4 & d5) - Landing, low speed, and takeoff performance will be evaluated and verified in a manner similar to that used in conventional large airplane testing. Landing and takeoff procedures, velocities, and distances will be determined for various vehicle weights, configurations, and atmospheric, runway, and cross-wind conditions. Rejected takeoff and approach/landing go-around characteristics will be determined. Airbreathing engine-out performance characteristics will be verified. Subsonic airplane flight performance will be verified, including best cruise, maximum endurance, climb performance, ceiling, and engine-out effects.

Buffet and Minimum Control (Figure 4.3-1 Test Requirement Nos. (V)c1 and (V)d1) - The booster stall and buffet speeds and flight characteristics shall be evaluated and verified. The absence of incipient spin or uncontrollable flight characteristics will be verified. Testing shall be accomplished in cruise configuration and with various jet flap and landing gear positions, and the effects of center-of-gravity position, airbreathing engine power setting, and engine-out will be evaluated.

The proper functional operation of the antispin/pitch augmentation device, Figure 4.3-1 Test Requirement No. (IV)(2), will be verified by operation at a safe, controlled flight condition during the horizontal flight test program.

Airspeed Calibration (Figure 4.3-1 Test Requirement Nos. (V)c7 and (V)d7) - The pressure airspeed and altitude pitot and static source survey will be conducted to select and calibrate the pressure instrument system. Angle-of-attack and vehicle configuration effects will be included. A currently developed calibration technique, or combination of techniques, such as trailing cone, tower fly-by, or pace airplane, will be utilized.

4.3.2.2 Vertical Flight Characteristics Verification Approach - The overall vertical flight test approach is described in the Space Shuttle System Test Plan, Section A Paragraph 7.5. The mission characteristics associated with prelaunch, launch, and ascent, including staging, will be evaluated and verified during the mated portion of the vertical flight test program. Booster poststaging mission characteristics - entry, cruiseback and landing, and postlanding and booster subsystems operation during all mission phases, will be verified in these vertical flight tests. The cruiseback and landing flight characteristics, and applicable booster subsystems operation, in the airplane flight mode will have been previously verified in the booster horizontal flight test program, described above and in Paragraph 7.4.2. The continued evaluation during the posttransition portion of the vertical flight program will mainly verify continued satisfactory design flight, characteristics and subsystems operation, after exposure to the actual launch, ascent, and entry flight environments.

Prelaunch (Figure 4.3-2 Test Requirement No. 1) - The Space Shuttle prelaunch characteristics, such as the procedures, techniques, and GSE involved in maintenance, onboard eheckout, erection and mating, transportation to the launch pad, etc., will be evaluated and verified by actual utilization during preparation for the flight test missions.

Launch (Figure 4.3-2 Test Requirement No. 1) - Launch phase characteristics including launch complex facilities and operations, checkout, crew and propellant loading and launch window capabilities, will be evaluated and verified in actual support of the flight test launches.

Ascent (Figure 4.3-2 Test Requirement No. 1) - Mated ascent flight characteristics and applicable subsystem operation will be evaluated and verified during the flight test program. The test approach has been summarized in Section A Paragraph 7.5 and in Figure 7.5-3. Mated vehicle guidance and control capabilities, utilizing the main propulsion system thrust vector control, will be evaluated and verified. Aerodynamic effects, including performance, loads, heating, and flow interaction effects, will be measured, correlated with design analyses and ground test results, and extrapolated to verify specification design capability to perform the design reference and alternate missions. Velocity/altitude data from the vehicle and tracking data will be utilized to verify the booster main propulsion system performance during ascent. Propulsion system data and tracking data will be compared and correlated with propulsion integrated test data to verify proper system operation.

Staging capability at nominal flight conditions or less critical conditions (very low dynamic pressures), will be verified. The vehicles will separate cleanly, without excessive attitude transients, with subsequent ignition of the orbiter main propulsion system. Staging capability will be demonstrated for various orbiter gross weights and center of gravity positions.

It is not planned to demonstrate booster main rocket engine-out or system abort modes during the mated vertical flight test program.

Entry (Figure 4.3-2 Test Requirement No. 2) - During the flight test program, the longitudinal, lateral, and directional stability and control characteristics of the booster will be evaluated and verified in the hypersonic, supersonic, and transonic flight regimes. Vehicle handling qualities, stability, control forces and power (ACPS and aerodynamic control surfaces), trim characteristics, and maneuvering capabilities will be demonstrated. The effects of gross weight and center of gravity variations will be evaluated. Specific control inputs to demonstrate stability and control capabilities will be programmed on later missions. Booster operation utilizing redundant branches of the stability augmentation and flight control system will be verified.

Velocity/altitude data from the vehicle and tracking data from the ground network will be utilized to verify the aerodynamic performance of the booster. This data will be correlated with wind tunnel data and extrapolated to verify, along with the actual flight performance results, the design crossrange and footprint capabilities of the booster.

Controllability and performance of the booster during the transition from high to low angle-of-attack flight at the conclusion of the entry phase will be verified. An antispin or pitch augmentation device, such as a parachute or solid rocket thrusters, will be provided on boosters S/N 2 & 3 for flight safety purposes during this portion of the flight envelope.

Cruiseback and Landing (Figure 4.3-2 Test Requirement No. 2) - The booster flight characteristics - handling qualities, stability, and control, and aerodynamic performance - during the posttransition glide will be evaluated and verified. Stall and buffet speeds and control characteristics will be spot-checked and verified for various flight conditions.

The airplane flight characteristics of the booster, previously evaluated and verified in the horizontal flight test program (Paragraph 4.3.2.1), will be verified for continued satisfactory design flight characteristics after exposure to be vibration, airload, and heat environments imposed by vertical operations. This will be mainly accomplished by nominal operational use and data collection during cruiseback to the landing at the launch site. Specialized test flight conditions will be minimized. However, a limited number of stability and control data points - stick raps, wind-up turns, rolls, etc. - will be conducted to spot-check the verification data obtained during the horizontal test program.

Postlanding (Figure 4.3-2 Test Requirement No. 2) - Postlanding characteristics of the booster, such as safing, crew egress, inspection, and maintenance, and the associated procedures, techniques, ground support equipment, etc., will be evaluated and verified by actual utilization. A preliminary evaluation, without the vertical mission environmental effects, will also have been obtained during the horizontal airplane mode flight testing.

An important part of the vertical flight test program will be the verification of subsystem operation in the booster during all mission phases. These subsystems are discussed individually in Paragraph 5.0.

5. SUBSYSTEM TESTING

Development of the major subsystem groups will be accomplished with the use of dedicated hardware setups assembled to perform functionally as a complete subsystem. Testing will be end-to-end by nature and will provide data for performance evaluation to support the CDR, and later to provide verification of specification compliance. Subsystem testing will include evaluation of nominal and off-nominal characteristics, performance limits, alternate and/or redundant operation mode, malfunction switching and redundant path capability, and evaluation of interface conditions.

The vehicle will be comprised of six major subsystem groups, namely: airframe, propulsion, avionics, crew station, power supply, and ground support equipment. These subsystems setups will be physically arranged to facilitate substitution of qualified components or software for prototype equipment or software to provide data for performance verification.

The approach to subsystem testing will vary based on design requirements and/or size, power, or installation peculiarities. Complete functional arrangements will be setup where cost effective. Sectionalized or partial assemblies of the complete subsystem, airframe, and propulsion groups, for example, will be implemented because of size and facility constraints. In such cases, assessment of total subsystem performance will be verified by the use of simulated interface stimulus of the unavailable portion of the subsystem. Final substantiation of performance, therefore, will, by necessity, be accomplished on the completely assembled vehicle.

5.1 Airframe Group Development and Verification Tests - The Airframe Group consists of the Structure, Landing and Deceleration, and Thermal Protection Subsystems. The Airframe test program defined herein was derived following a systems approach to test requirement recognition and an integrated program approach to test planning.

The system and vehicle specifications and criteria, and the specific designs have resulted in sensitivities which are the basis for requirements to test. These test requirements have been coalesced to recognize or identify the scopes of the major test programs. Following the pre-established test philosophies and criteria (Section A, Paragraph 3.0), the approaches to test implementation were selected which provide resolution of the various technical sensitivities in an efficient program. The advantage of this planning approach is the derivation of the overall most desirable (technically) and cost effective test program. A slight disadvantage of this integrated approach is that a technology discipline ordering of the testing is not altogether obvious.

To promote a better understanding of the individual technology considerations which have been integrated into the Airframe Group tests, test plan summaries for the Airframe Design, Materials and Processes, Structural Dynamics, and Thermodynamics technologies are presented in Sections 5.1.2 through 5.1.5, respectively, as a preface to the Airframe Test Plan. Within the summary test plans the technology applicable test philosophies and approaches are indicated to provide a base for the test implementation approaches. The airframe test plan generation flow is shown in Figure 5.1-1.

AIRFRAME TEST PLAN FLOW

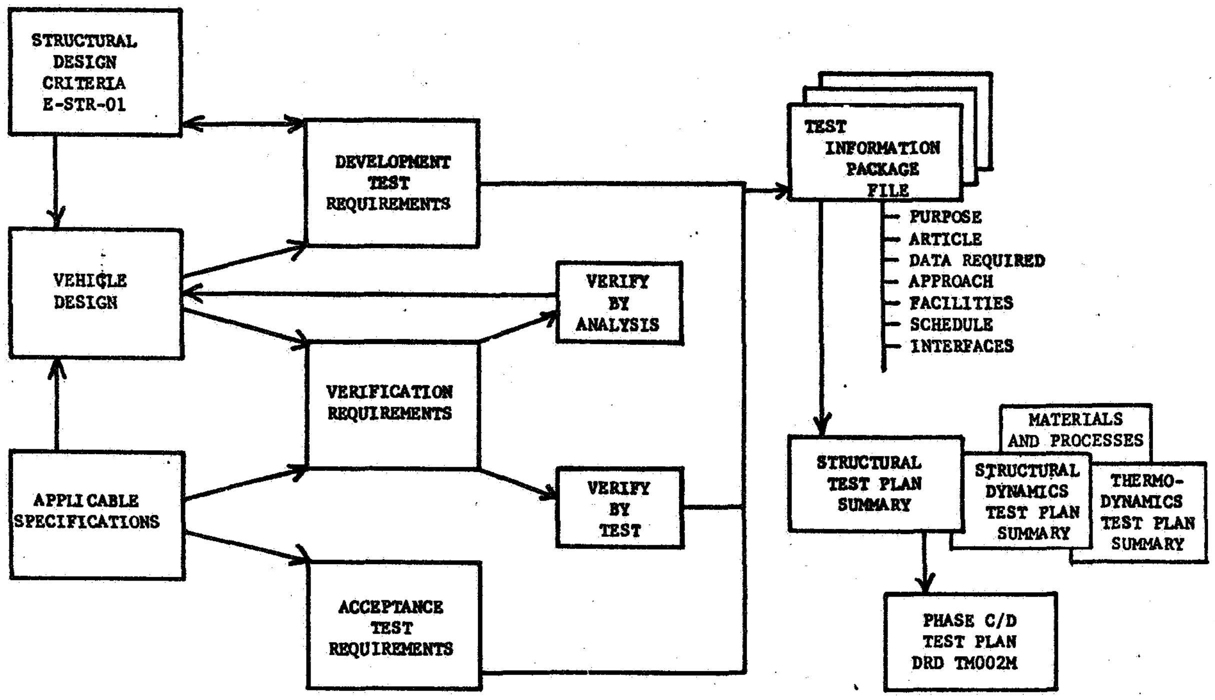


FIGURE 5.1-1

5.1.1 Description of Configuration

5.1.1.1 Booster Arrangement - The single body canard booster (configuration 20A) structural arrangement is depicted in the general arrangement drawing, Figure 5.1-2.

The body volume is primarily devoted to propellant containment, a forward LOX tank of a cylindrical and 4 conical elements and a separate aft cylindrical hydrogen tank. Both employ spherical segment end domes. Forward of the LOX tank, a nose fairing structure contains the pressurized crew compartment and an unpressurized equipment stowage space. This space houses the LOX vent system, the forward attitude control propulsion nozzles with associated valving, the cockpit environmental control and life support system components, and high pressure gas storage.

The intertank bay, providing access for services to the airbreathing engine installations in the jet flap canard, also functions as structural carry through for these surfaces and stowage and support for the 4-wheel forward landing gear bogie. The remaining intertank volume is devoted to the LOX sump and feedlines, the hydrogen tank vent system plumbing and components, stowage of JP-4 fuel for the airbreathing engines, and cryogenic propellant stowage for the attitude control propulsion system. The forward orbiter support and separation actuator is also located here.

The canard surfaces contain 5 airbreathing engines on each side, a controllable trailing edge jet flap surface, and movable engine inlet lips which are closed and sealed for engine protection during ascent and reentry. The bottom surfaces of these assemblies are completely removable for engine access and replacement.

Behind the hydrogen tank an aft body/thrust structure performs multiple functions. It supports the main engines (12 at 550,000 lbs sea level thrust each), and also doubles as pad tie-down structure and a wing carry-through box. The lower forward part of this volume provides stowage and support for two main landing gear 4-wheel bogies. The remaining space is filled with a hydrogen tank sump, main engine feedlines, 3 auxiliary power generation units and power, propulsion, control and electrical system secondary runs.

The wing and fin are of basically conventional construction except that the wing main box is deeply notched at the forward end to avoid the LH_2 tank dome. The result is an abnormally large leading edge torque box. To minimize the deflection and aid in sealing the special wing fairing TPS, a tie link is attached to the tank wall. Integral tankage for JP-4 fuel is also provided in the main box.

The aft orbiter attachment links, falling in the middle of the LH_2 tank, require special reinforcement of the tank shell and large external load spreading fittings.

CANARD BOOSTER
STRUCTURAL ARRANGEMENT

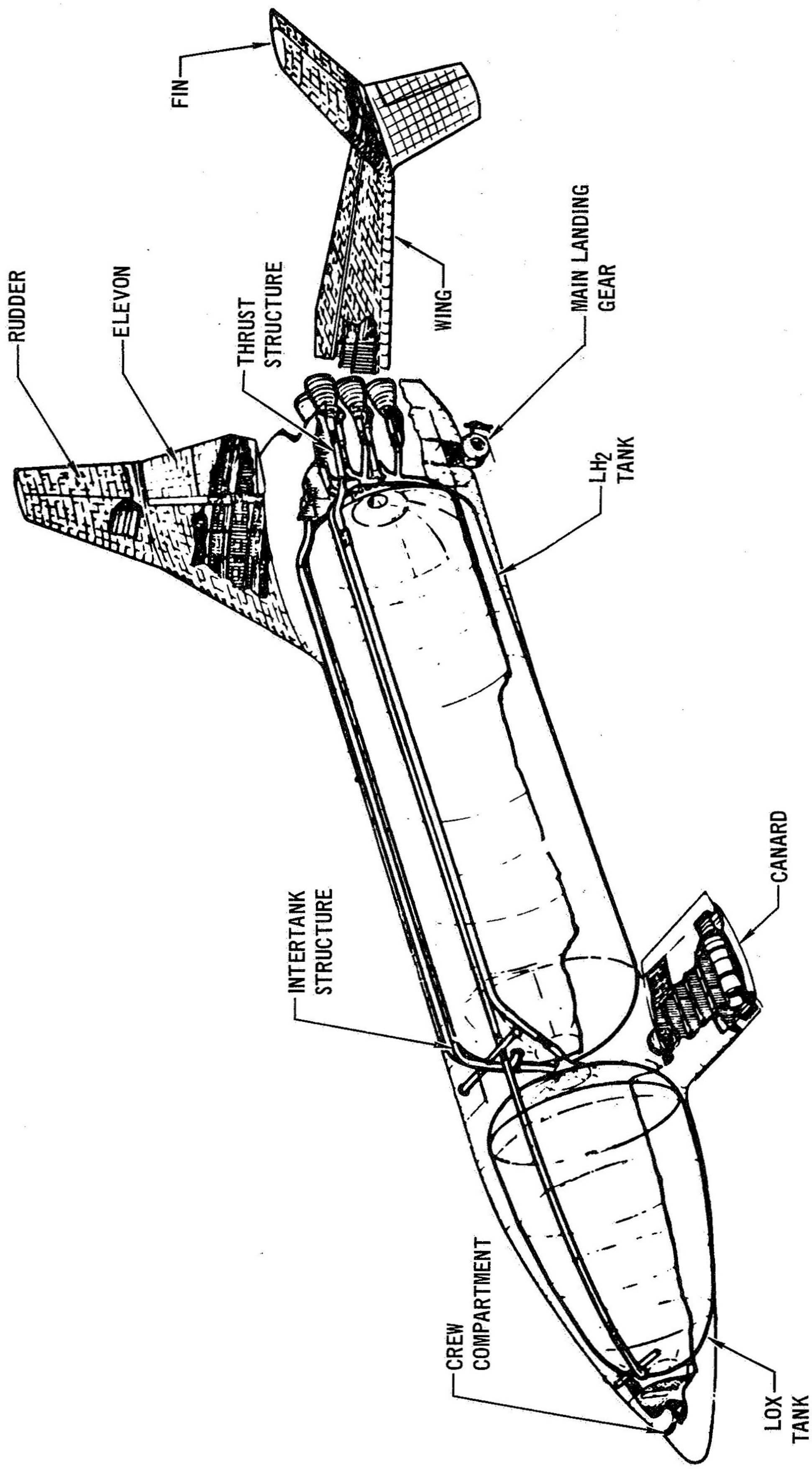


FIGURE 5.1–2

The entire exterior surface is covered with a thermal protection system employing Hardened Compacted Fiber (HCF) bonded to stiff substrate panels.

5.1.2 Structural Technologies Summary and Test Requirements - The purpose of this summary is to coalesce basic philosophies and criteria, requirements and selected approaches for the Space Shuttle booster structural adequacy verification tests. Emphasis has been placed upon identifying those tests which are essential to the establishment of flight-worthiness of the booster airframe, either singly or mated, with the orbiter.

The philosophies and criteria followed in the identification of the structural test programs are as follows:

(a) Structural test requirements are sensitive to specific design, therefore, the test program will address the MDC baseline vehicle -
  - o Canard booster, see Figure 5.1-2 for structural arrangement

(b) Verification may be accomplished by various balances of assessment and test. Analytical effort will be used as the primary method of verification to minimize test activity.
  - o All pressure vessels will be proof pressure tested once during manufacturing
  - o Fail safe mode designs will be verified analytically
  - o Designs having a factor of safety of two (2) or more will be verified by assessment
  - o Safe life designs will be verified by assessment except for Category 1 safe life designed structures

(c) Tests shall be performed to demonstrate structural adequacy only for the one most critical envelope derived from consideration of all loading sources and/or flight phases.

(d) All structural verification tests will be performed on full scale flight-quality hardware.

(e) Design development tests will be performed when necessary to provide analytical methodology authentication, confirm feasibility or design advantage, or identify failure modes. Maximum use will be made of development test data to minimize or eliminate verification testing.

(f) Minimum amounts of hardware will be dedicated to test use.

(g) Maximum use will be made of Phase B and supporting CRAD generated data to obviate further testing, e.g., Phase B Supplemental propellant tank cylinder test.

Requirements to be partially fulfilled by the structural test program are shown in Figure 5.1-3.

With the basic objective of test program cost effectiveness, test plans are indicated which are aligned to provide necessary test data in consonance with program phasing and vehicle design status taking advantage of test objective integration and existing test facility utilization. Because the structural sensitivities are the dominant factor in the selection of discrete test hardware, the structural test programs provide a test hardware foundation for the development of test information for other than Design and Strength technologies. It is therefore necessary to provide a comprehensive fulfillment of test requirements while providing a test hardware base which is adequately flexible to provide extended test data generation. The approach to vehicle airworthiness verification, in addition to normal manufacturing acceptance tests, is through a minimal structural development test program and structural verification of the airframe using major sections. The selection of airframe verification test sections and their configuration is based upon knowledge of structure strength and/or stiffness criticalities in relationship to anticipated loads and environments, confidence in analysis, materials

STRUCTURAL VERIFICATION TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
(1) The airframe group systems shall be verified to be structurally adequate and functionally operable (if applicable) while subjected to the combinations of natural and induced environments, based on the structural design criteria, which establish the structural design requirements of the system.	Necessary to verify adequacy of design.
(2) Test articles shall be selected and test conditions imposed which fulfill the greatest range of technical requirements using the minimum amount of test hardware. The sensitivities of design, strength, thermodynamics, structural dynamics, propulsion and loads technologies shall be integrated in defining the test program, consistent with existing facilities capabilities.	Necessary to economy of program.
(3) The structural verification test program shall be scoped and programmed to provide test data in consonance with program milestones while using less than an entire airframe for dedicated structural test purposes.	Necessary for test program economy.
(4) The test program shall include, as applicable, integrated methods of obtaining test data related to influence coefficients, dynamic response, (low level modal response, and POGO), safe life, ultimate strength, thermal effects, and vibroeadoustic effects.	Necessary for efficient hardware.
(5) Test hardware shall not, in general, be tested to failure to determine a design margin.	Necessary for effective utilization of test hardware.

FIGURE 5.1-3

STRUCTURAL VERIFICATION TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
(6) The energy absorption characteristics of the landing gear systems shall be established and their ultimate strength verified. Environmental synergisms related to heating and exposure to reduced atmospheric pressure shall be considered in establishing test conditions.	Necessary to verify landing gear system compatibility.
(7) Vehicle deceleration devices shall be tested to verify deployment, response, and adequacy under induced loads.	Necessary to substantiate design.
(8) The TPS shall be tested to verify adequacy for natural and induced environment design requirements. Special attention shall be given to panel dynamics (including acoustic response), heat transfer, and the synergistic effects of combined environments which may preclude dissociation of test environments.	Necessary to substantiate TPS design.
(9) TPS designs of material applications that are adequately similar between booster and orbiter vehicles shall be tested only to the most critical environments of either vehicle.	Duplication of test eliminated for economy.

FIGURE 5.1-3 (Cont.)

used, safety factors, similarities to previous structural applications, criticality classification, and manufacturing approaches. The Booster airframe design/strength structural test flow is shown in Figure 5.1-4. Test descriptions may be found in the referenced test plan sections.

The Materials and Processes testing will provide structural design data for materials or processes under new application or those properties not adequately documented.

Structural development tests are required for certain unprecedented designs and/or those designs for which analytical methods are empirical in nature and the validity of the analysis requires authentication. These tests will be performed early in the program to establish a feasibile design base which has been demonstrated (either analytically or by test) to be the most advantageous design by virtue of weight, strength, cost, manufacturability, etc. The development tests data will be used wherever possible to reduce or even eliminate verification testing by virtue of correlative analysis.

The verification of the airframe by testing of the major sections indicated was rationalized from the predominant local design sensitivities within the baseline vehicles.

For test implementation the test section boundary conditions will be identified and the necessary boundary support test structure will be designed and fabricated. To minimize special boundary condition simulation, compatibility tests will be performed at the next level of assembly whenever possible. The Major Structural tests identified will provide assurance that the designed structures will suitably sustain their most critical mission or operational loads and that the applicable design criteria have been met.

STRUCTURAL TEST PROGRAM FLOW

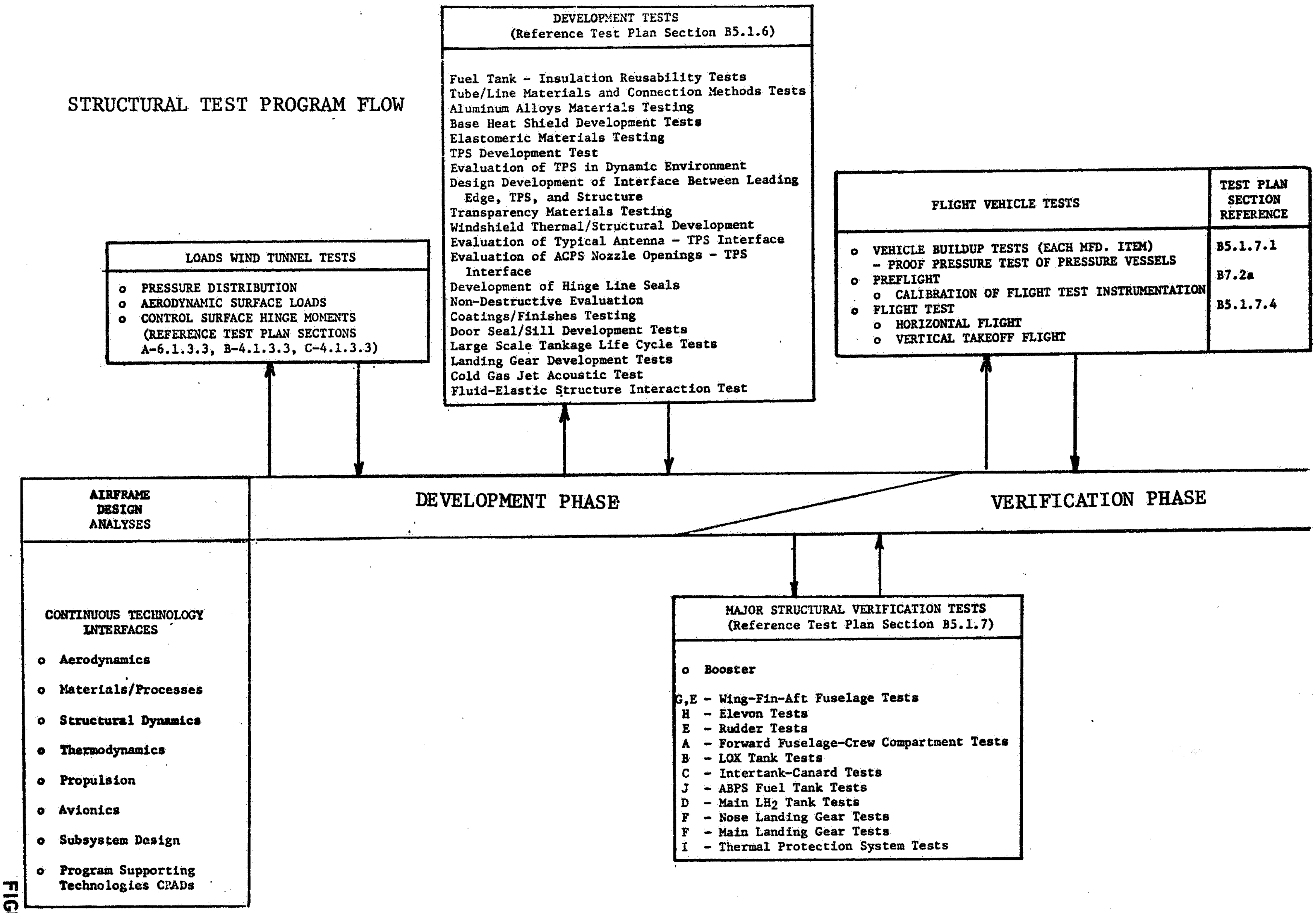


FIGURE 5.1–4

Prior to first vehicle flight the airframe will be subjected to static structural loads (not exceeding design or proof loads) to provide calibration of flight test instrumentation.

The flight test program will demonstrate the structural adequacy of the airframe through the measurement and correlation of flight induced loads and structural responses. Functional compatibility of airframe sections (control surfaces, doors, landing gear, etc.) will be flight demonstrated during the normal course of the flight test program.

The Airframe structural tests described will provide necessary design feasibility assurance, analytical methods substantiation and improvement, and physical demonstrations of the adequacy of the airframe to sustain its most critical loading conditions. The approach provides for local criticality adequacy demonstration, gives program flexibility, enables extensive use of existing test facilities, and provides an acceptable hardware base for thermodynamic and structural dynamics testing.

5.1.3 Materials/Processes Technology Test Summary and Test Requirements - The objective of the materials/processes technology is to provide essential material characteristics and design properties data to the vehicle development technologies.

The philosophies applied in establishing materials/processes testing are as follows:

(a) Maximum use shall be made of existing capabilities and techniques to preclude basic materials/processing development.

(b) Tests will be performed in accordance with standard test methods where they exist, e.g., ASTM, MIL-STD, MSFC-STD.

(c) Close scrutiny of supporting technology programs will be maintained and their results applicability will be assessed.

(d) Testing will be performed as required to statistically fill technical data voids. Adequate data range overlap will be provided to substantiate the use of existing data and the correlation of new data.

(e) The material application data requirements of the various technologies will be coalesced to establish testing programs which will generate the required data without extraneous or overlapping test efforts.

The materials/processes requirements to be partially fulfilled by tests are shown in Figure 5.1-5.

The approach to materials/processes data acquisition is, in order of application, by research and assessment of already documented results; evaluation of in-process or planned supporting technology efforts to determine the applicability of the effort and/or submit recommended changes to the effort; performing laboratory tests to generate the data. Initial materials and processes tests will be development tests by virtue of their objectives of acquiring new data and verification of processes in the support of vehicle design and development. Materials and processes acceptance tests will be performed routinely as a quality control procedure throughout the hardware fabrication effort.

The materials/processes development test program considerations, relationships and required materials tests identified are reflected in Figure 5.1-6. Test descriptions may be found in the referenced test plan sections. The review process will follow a continuous and orderly assessment of materials and processes considered for application by the various technologies in the design of the vehicle systems. These materials/processes will be discreetly reviewed for assurance that the best or optimum application has been specified in the system designs. This review will also determine that adequate information is available or pending to allow reliable design application or that it is necessary to perform selective tests to establish design application data. The specific test requirements recognition follows closely with specific detail designs wherein particular environments and design complexities are recognized and weighed against available knowledge. It is thus impossible to quantitatively identify all of the specific materials/processes test requirements in advance of detail design effort. However, beginning with the start of detail design in Phase C, additional test data requirements will be identified and tests will be implemented to establish a firm foundation upon which to base the final vehicle systems designs. Tests generally will be prescribed to fill critical open matrix positions in a hypothetical multidimensional materials/processes/properties data status matrix with parameters as considered in Figure 5.1-6.

Most of the materials tests will be of the coupon type and test implementation will be possible in many existing materials laboratories. The approach to test site selection for rudimentary materials tests will be to select a capable laboratory within the contractor's facilities near the data requisitioning technology. Existing NASA Laboratories capabilities will be considered in lieu of major contractor facility construction or modification if contractor capabilities do not exist.

The evaluation of processes must be closely aligned with the process application site plans and the technologies proposing process utilization. Therefore, contractor test laboratories will be considered as the primary source of process testing and pilot processing evaluation. The processing scale up or establishment of production processing systems will then naturally follow through to the production process certification and the establishment of process quality standards and acceptance test procedures.

MATERIALS/PROCESSES REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
(1) The combined storage and service life time of the vehicles is to be ten (10) years with at least 100 missions capability following a cost effective refurbishment and maintenance program.	A Level I imposed requirement.
(2) Where new materials or existing materials under new conditions are to be used, adequate testing shall be performed to statistically identify material property values.	To provide design information to assist attainment of minimum weight structures.
(3) Where commonality exists between Booster and Orbiter materials/processes applications, test programs shall be scoped to encompass the most severe application assessment.	Provides cost effectiveness through commonality and elimination of redundant testing.

FIGURE 5.1-5

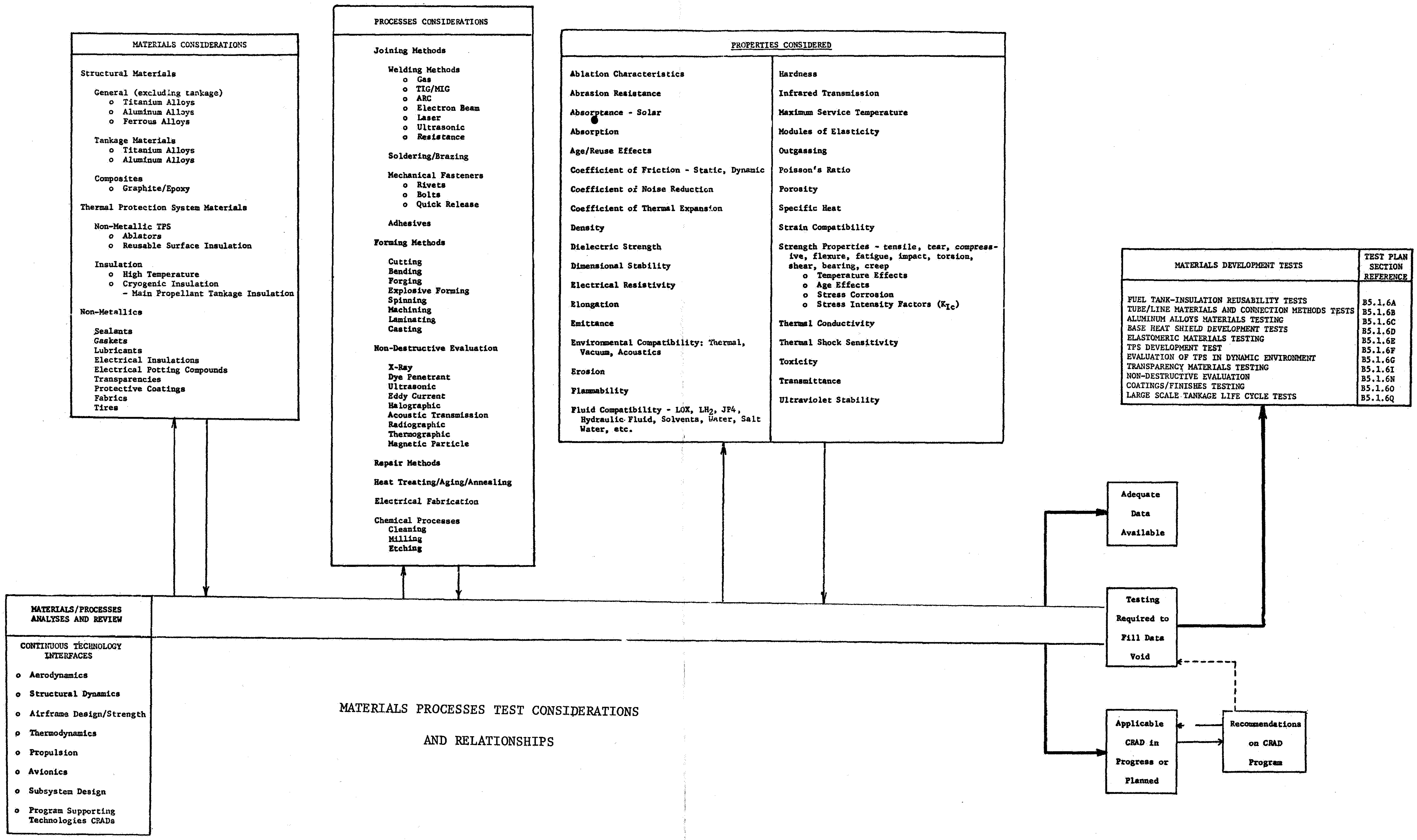
5.1.4 Structural Dynamics Technology Test Summary and Test Requirements - The principal philosophies applied for structural dynamics testing are as follows:

(a) The primary method of structural dynamics verification will be by analysis.

(b) Dynamics Models will be used to enhance analytical approaches during vehicle development.

(c) Minimal hardware will be dedicated to structural dynamics testing and a structural dynamics test airframe will not be required as adequate data can be obtained from model, section, and nondestructive flight vehicle tests.

(d) The structural dynamics tests which are performed (other than associated with safe life) will be nondestructive and will be integrable with other test program requirements to the greatest extent possible.



MATERIALS PROCESSES TEST CONSIDERATIONS

AND RELATIONSHIPS

FIGURE 5.1-6

The basic structural dynamics requirements to be partially fulfilled by tests are shown in Figure 5.1-7.

The approach to structural dynamics verification is through analyses substantiated by test. Correlation of analytical and experimental data will be done on a continuous basis. The results of these analyses will be utilized to provide assurance that the analytical results are accurate descriptions of vehicle characteristics and stability margins.

Tests will be performed to support dynamics analyses for all phases of individual and mated vehicle operations. These include prelaunch, ascent, separation, postentry, horizontal flight and landing/taxi phases. In performing the tests, it is a policy that test requirements are integrated if possible so that maximum benefit is obtained from each test. Consequently, in planning structural dynamic tests, maximum use of test hardware and experimental systems indicated to be required by other technologies is emphasized.

The structural dynamics data will be obtained from ground test efforts, conducted to supply data for the establishment or confirmation of analytical solutions of vehicle dynamics, followed by flight testing wherein horizontal and vertical flight are demonstrated. The structural dynamics test requirements will be met by a program aligned to provide necessary test data in consonance with program phasing and vehicle design status taking advantage of integrated test activities to minimize program costs and maximize test hardware utilization. The structural dynamics programmatic test flow is shown summarily in Figure 5.1-8 and the referenced test plan sections should be consulted for further descriptions of the identified tests.

The wind tunnel test programs will provide basic design dynamic environment data and modeled vehicle response data outputs. This information is fundamental to the establishment of structural designs which properly consider the dynamics of ground wind, and flight phase environments with primary emphasis on flutter, transonic buffet, and separation dynamics. Ground tests using dynamic models will be performed to enhance analytical techniques, identify critical design parameters and/or provide characterizations of vehicle or vehicle component dynamics. The fidelity of the models will be consistent with cost effectiveness and will include details necessary to provide essential information. Model scales will be based upon rational structural scaling and compatibility with existing test facility capabilities.

Structural dynamics considerations and requirements will be incorporated into the development and verification tests of vehicle subsystems. Subsystem response characteristics will conversely be incorporated into dynamics analyses. Functional component environmental qualification requirements will be realistically and iteratively evaluated for compatibility with expected use.

The structural adequacy of the vehicles will be demonstrated by the testing of major structural sections. Consistent with this approach, the structural dynamics analyses will be closely coordinated with the structural analyses models. The need for structural dynamics data will be fulfilled by integrating structural dynamics requirements into the airframe major section tests. Influence coefficient data and/or low level modal response data will be obtained from the major section test articles. In addition, acoustic environment safe life sensitive components will be evaluated as well as vibro-acoustic transfer function assessments of the crew compartment. As a final verification of vehicle separation functionality and dynamics, a single plane mass-inertia model will be used to perform separation demonstrations.

As a final phase of propulsion system verification, a Propulsion System Integration test unit of each vehicle will be assembled. These units will be comprised of flight destined fuselage sections with fuel delivery and control systems, tankage, thrust structure, engines, and TPS incorporated. The units will be erected on a launch pad and cold flow and hot fire engine integration tests performed. As a culmination of basic engine and fuel system component verification tests, wherein dynamic coupling characterization data will be obtained at the component level, the Propulsion System Integration test units will provide test articles which will be used to obtain local structural modes, fluid-structure coupling; subsystem acoustic environments verification and thrust structure vibro-acoustic verification in conjunction with the propulsion systems tests.

Prior to first horizontal flight the separate vehicles will be subjected to nondestructive ground vibration tests in the horizontal attitude to provide a final check on vehicle mode shapes and frequencies used in flutter stability analyses. Prior to first vertical mated flight the mated vehicles will be subjected to a nondestructive horizontal ground vibration test to provide final checks on mated vehicle mode shapes and frequencies used in flutter and POGO stability analyses. The flight test program will passively demonstrate flutter and POGO stability, will verify crew and subsystem environmental compatibilities, and will provide data which may be used to further substantiate analytically defined stability margins. Flutter will not be intentionally initiated by exciter mechanisms during either the vertical or horizontal flight test programs.

The structural dynamics test program as described will provide the necessary design information, analytical correlations, and physical verifications to provide a high confidence that vehicle dynamic requirements are met. The approach makes maximum use of technical and test hardware integration to provide a low risk - low test dedicated cost program.

STRUCTURAL DYNAMICS REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
1. The separation system shall be verified to be functionally operable while subjected to the combinations of natural and induced environments, based on the structural design criteria, which uniquely establish the structural design requirements and be capable of sustaining loads and environments in combination throughout its design life.	The vehicle separation function must be verified to be of low risk.
2. The fluctuating pressure loads and distributions, aerodynamic control surface loadings and flutter boundaries shall be determined for the mated vehicles for ascent through staging. The individual vehicles postentry flight condition of transonic buffet and flutter boundaries shall be determined.	Tests necessary to establish design environments and substantiate adequate stability margins exist in the vehicle designs.
3. Tests shall be performed on components, models, and/or assembled vehicles to provide data for the enhancement of analytical models used to develop a high confidence that oscillatory and nonoscillatory instabilities or excessive dynamic response will not occur at any point along the design operational profile which could result in structural failure, endanger the crew and/or passengers, or jeopardize the mission objectives.	Tests are required to define environment criticalities and correlate hardware characteristics with predicted values used in the dynamics analytical models. Specifically related to the dynamics analysis of the complete vehicle assemblies in the individual and mated vehicle configurations.

FIGURE 5.1-7

5.1.5 Thermodynamics Technology Test Summary and Test Requirements – The philosophies applied in relation to thermodynamics testing are as follows:

(a) Thermal environment prediction will be by combinations of analysis and test. Analysis will be fundamental to the classic problem solutions and testing will be implemented only to extend analytical capabilities or assess unconventional sensitivities.

STRUCTURAL DYNAMICS TEST FLOW

STRUCTURAL DYNAMICS ANALYSES

CONTINUOUS TECHNOLOGY INTERFACES
- o Aerodynamics
- o Materials/Processes
- o Airframe Design/Strength
- o Thermodynamics
- o Propulsion
- o Avionics
- o Subsystem Design
- o Program Supporting Technologies CRADs

DEVELOPMENT PHASE

WIND TUNNEL TEST PROGRAMS	TEST PLAN SECTION REFERENCE
o MATED VEHICLES – ELASTIC MODELS o DETERMINE RESPONSE TO GROUND WINDS o ESTABLISH ASCENT FLUTTER BOUNDARIES o DETERMINE TRANSONIC BUFFET LOADS – RIGID MODEL o DETERMINE ASCENT FLUCTUATING PRESSURES o SEPARATION DYNAMICS	A6.1
o BOOSTER VEHICLE – ELASTIC MODEL o DETERMINE POSTENTRY TRANSONIC BUFFET LOADS o DETERMINE POSTENTRY FLUTTER BOUNDARIES – RIGID MODEL o DETERMINE POSTENTRY FLUCTUATING PRESSURES o SURFACE PANELS – FLUTTER BOUNDARIES FOR CRITICAL SURFACE PANELS	B4.1

STRUCTURAL DYNAMICS MODEL TESTS	TEST PLAN SECTION REFERENCE
o BOOSTER – RIGID MODEL WITH COLD GAS JET o DEFINE NEAR FIELD ACOUSTIC LEVELS DURING ABE OPERATION	B5.1.6S
o LIQUID-LINE/TANKAGE MODELS o DEFINE TANK BAFFLING REQ'MTS o STRUCTURE-FLUID INTERACTION	B5.1.6T
o MATED VEHICLE DYNAMICS MODEL o DEFINITION OF INTERSTAGE CONNECTION TRANSFER FUNCTIONS	A5.2

MAJOR AIRFRAME GROUP TESTS	TEST PLAN SECTION REFERENCE
o LOW LEVEL DYNAMIC RESPONSE OF MAJOR AIRFRAME SECTIONS o WING-AFT FUSELAGE – THRUST STRUCTURE o FIN o RUDDER + ACOUSTIC SAFE LIFE o ELEVON + ACOUSTIC SAFE LIFE o LANDING GEAR DOORS o TPS (20%) + ACOUSTIC SAFE LIFE o MAIN PROPELLANT TANKS + FLUID LEVEL EFFECTS (LOX) o INTERTANK STRUCTURE AND CANARD + JET FLAP ACOUSTIC SAFE LIFE o CREW COMPARTMENT o LANDING GEAR DYNAMICS + STRUT CALIBRATION + NLG SHIMMY o VIBRO-ACOUSTICS – CREW COMPARTMENT o DATA FOR CREW RIDING QUALITIES AND VERIFICATIONS OF SUBSYSTEMS ENVIRONMENTS	B5.1.7.2
o SEPARATION DYNAMICS – SEPARATION SYSTEM PLANAR MODEL o SEPARATION DYNAMICS OF MASS-INERTIA SYSTEM	A5.3

PROPULSION SYSTEM TESTS	TEST PLAN SECTION REFERENCE
o MAIN ENGINE TESTS (BY VENDOR) o ACOUSTIC LEVELS o THRUST CHARACTERISTICS o ENGINE TRANSFER FUNCTION	B5.2.1
o ABE TESTS (BY VENDOR) o ACOUSTIC LEVELS THRUST CHARACTERISTICS	B5.2.3
o PROPULSION SYSTEM COMPONENT TESTS o LIQUID-LINE COUPLING FUNCTIONS	B5.2
o PROPULSION SYSTEM INTEGRATION TESTS – COLD FLOW TEST – HOT FIRE TEST o LOCAL STRUCTURE MODES o FUEL LINE-STRUCTURE COUPLING o STRUCTURE-FLUID INTERACTION o VIBRO-ACOUSTIC EVALUATION OF THRUST STRUCTURE o VERIFICATION OF EQUIPMENT ENVIRONS.	B6.4

VERIFICATION PHASE

FLIGHT VEHICLE TESTS (NONDESTRUCTIVE)	TEST PLAN SECTION REFERENCE
o GROUND VIBRATION TEST – BOOSTER o HORIZONTAL TEST BEFORE HTO + PROVIDES FINAL CHECK ON DYNAMIC MODEL OF BOOSTER USED IN FLUTTER STABILITY ANALYSES.	B7.2b
MATED VEHICLES o HORIZONTAL TEST BEFORE VTO + PROVIDES FINAL CHECK ON DYNAMIC MODEL OF MATED VEHICLE USED IN FLUTTER AND POGO STABILITY ANALYSES.	A7.3
o FLIGHT TEST – HORIZONTAL o DEMONSTRATE FLUTTER STABILITY o OBTAIN DATA FOR CREW RIDING QUALITIES AND VERIFICATION OF SUBSYSTEM ENVIRONMENTS – VERTICAL o DEMONSTRATE FLUTTER AND POGO STABILITY. o OBTAIN DATA FOR CREW RIDING QUALITIES AND VERIFICATION OF SUBSYSTEM ENVIRONMENTS. o CONFIRMATION OF SEPARATION DYNAMICS RESPONSE.	B5.1.7.4

FUNCTIONAL SUBSYSTEMS TESTS	TEST PLAN SECTION REFERENCE
o ENVIRONMENTAL QUALIFICATION REQUIREMENTS o AVIONICS GROUP o CREW STATION GROUP o POWER GROUP	B5.3 B5.4 B5.5
o SYSTEM RESPONSE CHARACTERISTICS – HYDRAULIC AND CONTROLS TEST UNIT o HYDRAULICS SYSTEMS o CONTROL SYSTEMS	B5.5.2

FIGURE 5.1–8

(b) Thermal/structural interrelationships can be adequately assessed by analysis supported by element tests.

(c) Minimal hardware will be dedicated to thermal testing and a thermal (or thermal-vacuum) test airframe will not be required.

(d) Simulated thermal environment tests include compromises which must be weighed into the test value determinations.

The primary thermodynamics requirements to be partially fulfilled by tests are shown in Figure 5.1-9.

The approach to thermodynamics verification is to establish a high confidence level in thermal environment predictions through analysis (both by empirical and similitude methods) combined with wind tunnel tests and thermal control system adequacy assessments by analysis and demonstration tests performed on elements or sections.

Tests will be conducted as necessary to support thermodynamics analyses for all sensitive vehicle operational phases. These include pre-launch, launch, ascent, separation, space environment, entry, horizontal flight and post flight. In test implementation the thermodynamics test requirements are integrated with those of other technologies where possible so that maximum value is obtained from each test. Consequently, in planning thermal tests, use of test hardware and experimental systems indicated to be required by other technologies is emphasized.

Thermodynamics test data will be obtained from ground development test efforts conducted to define environmental levels and design thermodynamic properties, ground verification tests conducted to substantiate the adequacies of the thermal control systems, and flight demonstration tests to finally authenticate design environments and thermal control system adequacies. Tests will be ordered to provide necessary data in consonance with program phasing and vehicle design status while being integrated into the individual test flows so as to not jeopardize the

THERMODYNAMICS REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
(1) Data and related information shall be acquired from wind tunnel tests of appropriately designed subscale models of the orbiter and booster mated in the ascent configuration or in the immediate proximity one to the other, or the assembly to the ground plane, such that the flow field of either vehicle is influenced by that of the other. Simulated flow conditions, within the practical limitations of existing facilities, will include the Mach and Reynolds number ranges associated with ascent and separation, vehicle attitudes, and aerodynamic control surface positions. The tests will acquire the following information:	Required for:
(a) Induced orbiter plume impingement upon the booster during both normal and abort separation.	Ascent trajectory analyses, stability and control analyses, abort analyses, loads analyses, and flight performance predictions.
(b) Aerodynamic heating of the launch configuration including that induced by engines operation.	Thermal environment definition and TPS and base heatshield design.
(2) Aerodynamic heating of the vehicle for conditions of entry, including assessment of heat transfer to the base region and main engine nozzles and heating of localized details such as windshield, leading edges, fillets, and TPS protuberances and gaps shall be determined.	Thermal environment definition and TPS design.
(3) The airframe group systems shall be verified to be structurally adequate and functionally operable (if applicable) while subjected to the combinations of natural and induced thermal environments, based on the structural design	Necessary to verify adequacy of design.

FIGURE 5.1-9

THERMODYNAMICS REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
criteria, which establish the structural design requirements of the system.	
(4) Environmental synergisms related to heating and exposure to reduced atmospheric pressure shall be considered in establishing test conditions on landing gear.	Necessary to verify landing gear system compatibility with design.
(5) The TPS shall be tested to verify adequacy for natural and induced environment design requirements. Special attention shall be given to panel dynamics (including acoustic response), heat transfer, and the synergistic effects of combined environments which may preclude dissociation of test environments.	Necessary to substantiate TPS design.
(6) TPS designs of material applications that are adequately similar between booster and orbiter vehicles shall be tested only as applicable to the most critical environments.	Duplication of test eliminated for economy.
(7) Verify the ability of the environmental control systems to satisfactorily maintain the personnel compartment(s), equipment bays, and other conditioned areas at design conditions for <u>temperature</u>, pressure, gas mixture content, humidity, and atmosphere purity.	Required for early development and verification or design, thereby reducing program risk or costly design changes during the flight test program.

FIGURE 5.1-9 (Cont.)

validity of subsequent testing. The thermodynamics programmatic test flow is shown summarily in Figure 5.1-10 and the referenced test plan sections should be consulted for further descriptions of the identified tests.

The initial wind tunnel test programs will provide external thermal load quantification and distribution data. This information is essential to the design of the thermal protection system with respect to maximum heating rates and total heat loads as they impact the TPS materials applications and weights. Heat transfer and flow visualization tests will be performed to enhance analyses to help assess the thermodynamic requirements of the thermal protection system. Localized sensitivities will be evaluated by larger models or special consideration of these areas to further refine thermodynamic requirements or constraints. These tests will encompass evaluations of vehicle base heating effects, propulsion exhaust effects (ACPS, Airbreathing engines), TPS panel flow leakage, sensitive mold line intersections or discontinuities, etc. Wind tunnel model scales will be selected on a fidelity/cost/facility capability/multiple use potential basis to help minimize the cost of the wind tunnel program.

The developed thermodynamic environments will be extended to define the thermodynamic environmental qualification requirements for the subsystem functional components. The development testing of the functional subsystems will conversely substantiate the system generated heat loads and thermal balance compatibilities. Thermal balance testing will be implemented on a component level to disseminate testing to existing test facilities.

The Airframe group tests will be aligned to incorporate thermal development and adequacy verification requirements. The structural adequacy of the vehicles will be demonstrated by the ground testing of major structural sections and the assembled airframes. Consistent with this approach and the stated thermal test philosophies, thermal environments will be imposed only for those tests wherein

THERMODYNAMICS TEST PROGRAM FLOW

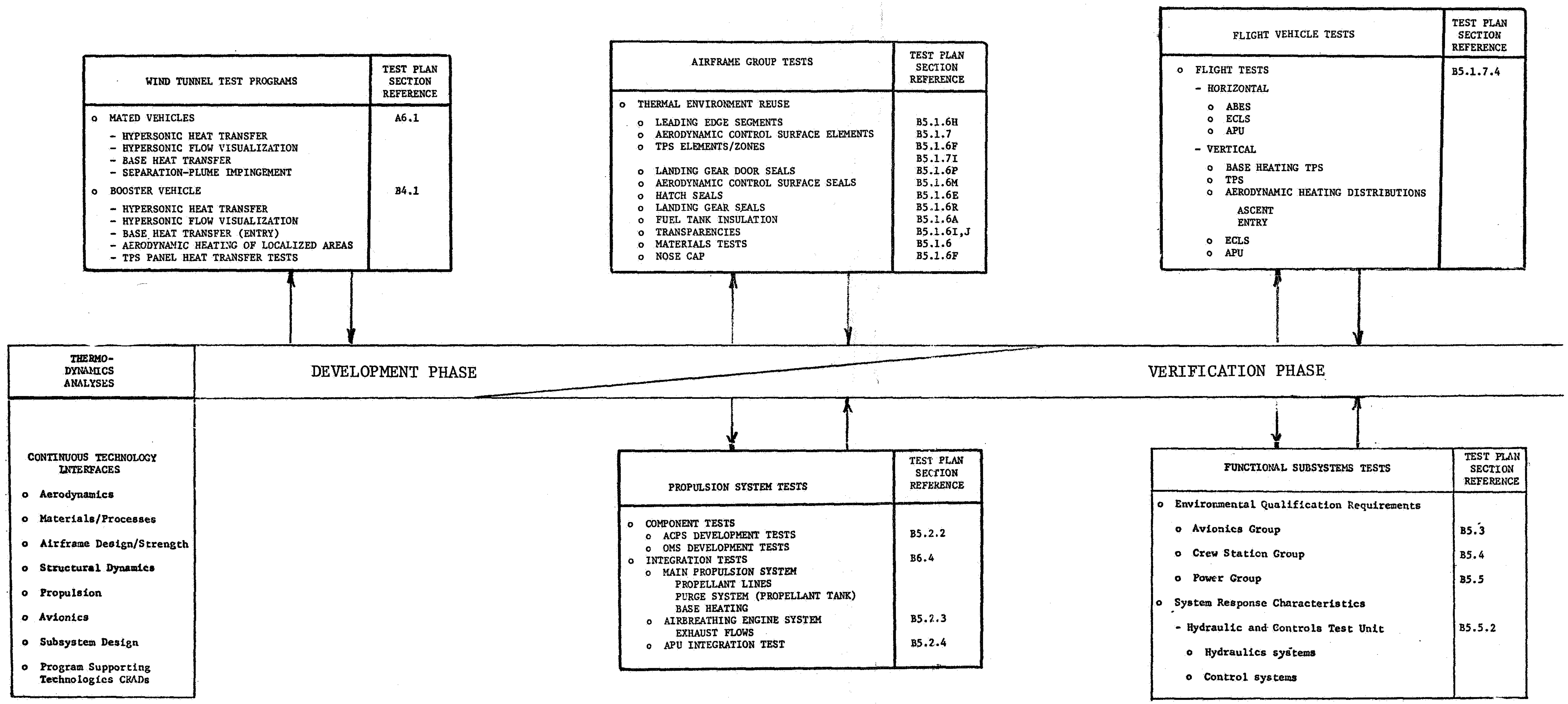


FIGURE 5.1-10

the effects of temperature or temperature gradients cannot be suitably compensated for analytically or by test loads adjustment. Because the TPS is modular in design and is "sized" for local heat loads, the verification testing of the TPS will also be modularized to demonstrate the thermal-structural adequacy and/or reusability of the various designs. This testing is thus broken down into element evaluations which will encompass design range application of thermal, structural, and structural dynamics (flutter/acoustics) loads for safe-life reusability and/or ultimate loads. It is anticipated that the TPS element testing will involve about 20 percent of the total system with the majority of the tests being associated directly with local considerations such as penetrations, joints, mold line intersections, etc. The scope of each of these tests is local design configuration sensitive and is, therefore, subject to limited definition within the Phase B program depth.

The propulsion system component tests will verify heat balance adequacies of the secondary rocket propulsion systems. During integrated main propulsion system tests the thermal compatibility of the system's elements will be verified and the adequacy of the propellant tank external purge system will be demonstrated. During main engine firing the vibro-acoustic adequacy of the base heating TPS will be demonstrated. The heat loads and thermal balance acceptability of the airbreathing engine and auxiliary power units will be substantiated during system integration tests.

Flight test efforts related to thermodynamics will be substantiative and demonstrative in nature. Flight test instrumentation will provide substantiation of thermodynamic environments throughout the flight profile. Flight demonstration of systems heat balance acceptabilities will provide final verification of system performance.

The thermodynamics tests described will provide the necessary design information, analytical methodology improvement, correlation between analysis and physical systems, and physical verifications to provide a high confidence in the thermal adequacy of the vehicle systems. The approach taken makes maximum use of technical and test hardware integration to provide a comprehensive and cost effective thermodynamics program.

5.1.6 Development Tests - Airframe development testing will be performed to generate design data; verify design concepts; substantiate analytical methods or aid in developing analytical techniques; establish design advantages of weight, strength, cost, manufacturability, etc. Development testing will be adequately flexible to allow rapid design effectivity evaluation and maintain test scopes within design objectives. While development testing is not specifically aimed at specification compliance demonstration, the test operations and test systems calibrations will be managed so that credible data is generated which can be used to reduce or eliminate verification testing by virtue of correlative analysis. Development test hardware will generally consist of coupon and element test articles, preproduction hardware, or design synthesis models.

The airframe development tests and the test implementation plans are presented in the following paragraphs. As a reader assist, a titular summary and subparagraph reference of development tests follows.

A. Fuel Tank - Insulation Reusability Tests

B. Tube/Line Materials and Connection Methods Tests

C. Aluminum Alloys Materials Testing

D. Base Heat Shield Development Tests

E. Elastomeric Materials Testing

F. TPS Development Test

G. Evaluation of TPS in Dynamic Environment

H. Design Development of Interface Between Leading Edge, TPS, and Structure

I. Transparency Materials Testing

J. Windshield Thermal/Structural Development

K. Evaluation of Typical Antenna - TPS Interface

L. Evaluation of ACPS Nozzle Openings - TPS Interface

M. Development of Hinge Line Seals

N. Non-Destructive Evaluation

O. Coatings/Finishes Testing

P. Door Seal/Sill Development Tests

Q. Large Scale Tankage Life Cycle Tests

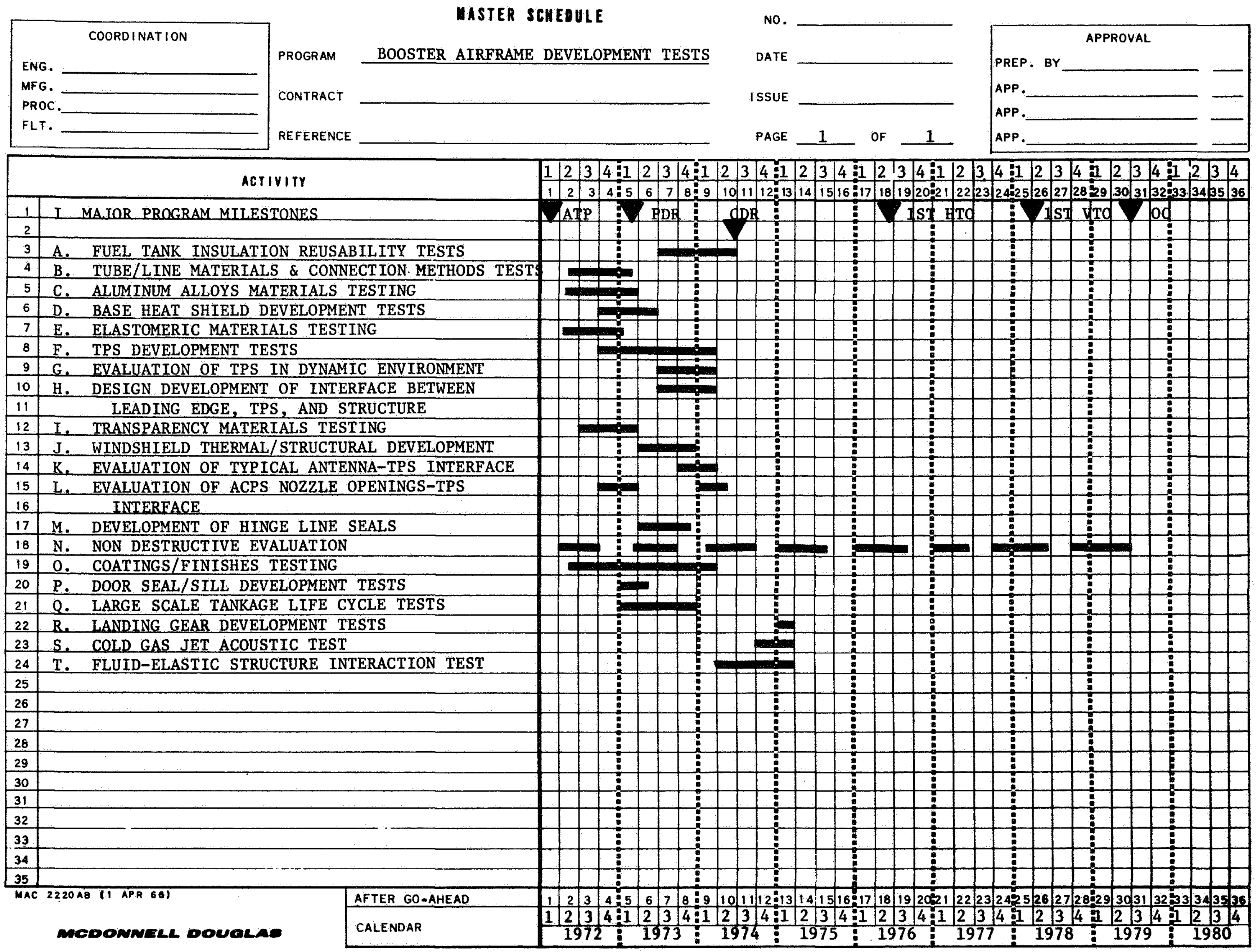
R. Landing Gear Development Tests

S. Cold Gas Jet Acoustic Test

T. Fluid - Elastic Structure Interaction Test

Development test schedules are shown in Figure 5.1-11.

A. Fuel Tank - Insulation Reusability Tests - The purposes of these tests are to evaluate and demonstrate the reusability of main propellant tank insulation installation and develop tank penetration techniques which provide acceptable reuse characteristics from strength and sealing aspects. The test article will be a test tank with approximate dimensions of 8 ft. diameter x 16 ft. long made from existing tooling capabilities. The tank construction will be representative of vehicle tank construction with representative tank penetrations included. The tank will be insulated and lined following baseline designs and processes. The tank will be subjected to repeated LH_2 fill/pressure/drain/heat cycles to assess the reusability of the insulation installation. Representative loads will be applied to penetration points to evaluate their seal integrity. Test data will include temperatures, pressures, loads, NDE results, and photographs. Tests will be performed by MDAC in the Sacramento Test Facilities. Test results are required prior to final design of the propellant tank and insulation installation. This test potentially may be combined with the objectives of the Large Scale Tankage Life Cycle Tests (Subparagraph Q. below) if timeline sensitivities can be met.


MASTER SCHEDULE
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PROGRAM BOOSTER AIRFRAME DEVELOPMENT TESTS
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3 A. FUEL TANK INSULATION REUSABILITY TESTS
4 B. TUBE/LINE MATERIALS & CONNECTION METHODS TESTS
5 C. ALUMINUM ALLOYS MATERIALS TESTING
6 D. BASE HEAT SHIELD DEVELOPMENT TESTS
7 E. ELASTOMERIC MATERIALS TESTING
8 F. TPS DEVELOPMENT TESTS
9 G. EVALUATION OF TPS IN DYNAMIC ENVIRONMENT
10 H. DESIGN DEVELOPMENT OF INTERFACE BETWEEN
11 LEADING EDGE, TPS, AND STRUCTURE
12 I. TRANSPARENCY MATERIALS TESTING
13 J. WINDSHIELD THERMAL/STRUCTURAL DEVELOPMENT
14 K. EVALUATION OF TYPICAL ANTENNA-TPS INTERFACE
15 L. EVALUATION OF ACPS NOZZLE OPENINGS-TPS
16 INTERFACE
17 M. DEVELOPMENT OF HINGE LINE SEALS
18 N. NON DESTRUCTIVE EVALUATION
19 O. COATINGS/FINISHES TESTING
20 P. DOOR SEAL/SILL DEVELOPMENT TESTS
21 Q. LARGE SCALE TANKAGE LIFE CYCLE TESTS
22 R. LANDING GEAR DEVELOPMENT TESTS
23 S. COLD GAS JET ACOUSTIC TEST
24 T. FLUID-ELASTIC STRUCTURE INTERACTION TEST
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AFTER GO-AHEAD
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CALENDAR
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1972 1973 1974 1975 1976 1977 1978 1979 1980
MAC 2220AB (1 APR 66)
MCDONNELL DOUGLAS

FIGURE 5.1-11

B. Tube/Line Materials and Connection Methods Tests - The purpose of these tests is to evaluate tube, duct and line materials and various methods of tube/line connection and develop the most reliable and weight sensitive methods for Shuttle application. Testing will be performed on test tube/line material elements to evaluate flare, braze, swage lock, welded, and new connecting devices and their applicability to potential tubing materials usage. Tests will be performed by MDAC. Test results and recommended tube/line materials and connection methods are needed prior to design of tube/line applications.

C. Aluminum Alloy Materials Testing - The purpose of these tests is to establish design material properties, welding processes and fabrication methods for new Aluminum Alloys. Tests will be conducted on material coupons. Testing will include the determination of properties of tensile, shear, flexure, fatigue, creep, and bearing strengths; fracture toughness; and the effects on the strength properties resulting from elevated temperatures, welding, forming, and mission reuse. Standard materials test methods and specimen configurations will be used to establish necessary design data and processing methods. Tests will be conducted primarily in the MDAC Materials Properties Laboratories. The compilation of this test data is prerequisite to detailed design of the most efficient material application.

D. Base Heat Shield Development Tests - The objective of these tests is to evaluate the performance of the insulated composite base heat shield concept when exposed to its flight associated thermal and acoustic environments. The test specimen will consist of representative segments and attachments of the base heat shield design. The test sections will be supported in test fixtures and subjected to repeated exposures of thermal and acoustic environment simulations. Test data will include temperatures, pressures, acoustic levels, and photographs. Tests will be conducted by MDAC-West. Test results are required prior to final design of the base heat shield system.

E. Elastomeric Materials Testing - The purpose of these tests is to establish design applicability or suitability of elastomer materials for their potential Shuttle environmental applications. Testing will include the determination of physical and mechanical properties and their associated relationships with aging/reuse and environmental compatibilities. Testing will employ standard test methods and standard test specimen configurations where applicable and will evaluate prototype designs of certain specific applications. Tests will evaluate seals, low burning fluorocarbon rubber (solid and sponge), and silicone rubber. Tests will be implemented primarily in MDAC Materials Evaluation Laboratories. The suitability of the material selections must be established before design use of the material can be made.

F. TPS Development Test - The objective of these tests is to develop the TPS configurations incorporating knowledge acquired from Phase B and CRAD effort. This is necessary to verify system concept and feasibility; and that system response to the mission environment is within prediction tolerance. The specimen is comprised of heat shield panels, support beams and struts, and retention devices and leading edge segments. Materials used will be ablators and HCF as established during the Phase B study. These specimens are second generation designs and reflect both Phase B study results and CRAD testing. Following modal survey testing, each test specimen will be repeatedly subjected to a simulated mission environment consisting of: (a) ascent aerodynamic pressures at room temperature, (b) ascent acoustic environment, (c) entry temperatures and pressures applied simultaneously, and (d) cruise flight aerodynamic pressures at representative temperature. The environment exposure will be repeated to assess the effects of multiple mission simulations. When simulating entry environment, tests will be performed in an altitude chamber to obtain insulative characteristics and performance at reduced pressure. Test data will include strains, deflections, loads, pressures, dynamic response, acoustic levels, temperatures, and photographs. Tests will be conducted in MDAC Thermal Structural Test facilities. Testing must be completed prior to TPS final design selection.

G. Evaluation of TPS in Dynamic Environment - The objective of these tests is to assess the thermal characteristics of the TPS panel systems when exposed to simulated entry flow and pressure environments. This testing is necessary to determine the effects of entry flow upon the TPS panel systems as generated from Phase B and CRAD testing efforts. This test will also provide a correlation between a gas dynamics environment and an infrared source environment (quartz lamps) to be used for the majority of thermal testing. Two test panels for each configuration with supports, fasteners, and joint covers will be mounted on simulated wing and fuselage structure. The panels will be repeatedly exposed to simulated entry heating and pressure profiles. Test data will include environment source flow, enthalpy, temperatures and pressures. Data acquisition points will correspond with those in the testing described in F. above so that a comparison can be made between the results of dynamic and static thermal environment sources. Testing will be conducted by MDAC using the USAF - AFFDL 50mw Electrogasdynamics Facility. Test data is required prior to final design of the TPS panel systems.

H. Design Development of Interface Between Leading Edge TPS and Structure - The objective of these tests is to determine the thermal and physical compatibility between the ablative leading edge and the adjacent TPS and structure as applicable to the wing and fin. The test articles will consist of representative leading edge-TPS system installed on typical wing and fin structure supports. The test support systems will provide boundary condition regulation. Testing will be conducted in a pressure-temperature profile environment. A gas dynamic test source environment will be used. Test data will include temperatures, pressures, relative displacements, and photographs. Testing will be conducted by MDAC using the USAF - AFFDL 50mw Electrogasdynamics Facility. Test results are required prior to final design of leading edge-TPS-structure interfaces.

I. Transparency Materials Testing - Testing will be performed to evaluate materials and installations applicable to optic and non-optic (antenna) transparencies. Testing will evaluate thermal-physical environment compatibilities of potential material applications. Considerations will include thermal degradation, transmission properties/quality, strength, electrical properties (for antennas), and impact resistance. Testing scope will include evaluation of basic materials as well as material application methods such as sealing, mounting and coating. Tests will be conducted at the coupon level. Tests will be performed in MDAC test facilities. The completion of these tests and data analysis must precede final transparency design selections.

J. Windshield Thermal/Structural Development - The objective of these tests is to evaluate the design of the windshield system for its thermal and structural applications. The test article will consist of a prototype windshield transparency installed in a frame and supported by representative local structure. Tests will be conducted to determine the thermal compatibility of the transparency with its design loads and installation design. The windshield will be subjected to thermal loads, pressure differentials, frame loadings, and impact tests to assess the acceptability of the design. Test data will include temperatures, loads, strains, deflections, pressures, impact resistance, and photographs. Testing will be conducted by MDAC-West. Test results are required prior to final design of the windshield installation.

K. Evaluation of Typical Antenna-TPS Interface - The objective of these tests is to determine the thermal compatibility and isolation of a typical antenna system installed in the TPS. The testing is necessary to develop an acceptable design for the integration of antennas with the TPS. A test antenna-TPS area with backup supports and insulation will be enclosed in a boundary conditioning test support. The specimens will be repeatedly exposed to gas dynamic-pressure environments simulating flight environments. Test data will include environment parameters of flow and enthalpy as well as temperatures and pressures. Testing will be conducted by MDAC-West using the USAF - AFFDL 50mw Electrogasdynamics Facility. Test results are required prior to final design of antenna-TPS interfaces.

L. Evaluation of ACPS Nozzle Openings-TPS Interface - The objective of these tests is to determine the effects of the ACPS nozzle openings in the TPS and establish thermal characteristics of the nozzle installation. The test article will consist of a representative TPS system with an ACPS nozzle installation. A test support system will provide test thermal boundary condition control. The test will be performed in a dynamic thermal and pressure environment with repeated exposures to determine any system degradation. Test data will include temperatures, flows, pressures, source enthalpy, and photographs. Tests will be conducted by MDAC-West using the USAF - AFFDL 50mw Electrogasdynamics Facility. Test results are required prior to final design of ACPS nozzle installation.

M. Development of Hinge Line Seals - The object of these tests is to develop a design configuration for thermal and gas flow seals for the wing-elevon and fin-rudder hinge line joints. Representative joint elements will be mounted in a test fixture and subjected to thermal, pressure differential, and relative motion cycle tests to determine the thermal and physical performance of the seal designs. Test data will include temperatures, dimensions, wear, leakage, pressures, and photographs. Tests will be conducted by MDAC-West. Test results are required prior to final design of hinge line seals.

N. Non-Destructive Evaluation - The purpose of this effort is to develop non-destructive evaluation (NDE) techniques applicable to the sensitivities of the Shuttle systems. Areas of consideration include the establishment of methods and intervals for the performance of NDE on the operational vehicle. The scope of NDE development effort includes material receiving/inspection, in process evaluation, post forming inspection, pre-flight acceptance, and post flight inspection. Sensitive areas of concern include primary structure, propellant tankage and thermal protection systems. The major complexity is related to the large size (areas to be evaluated) of the vehicle and accessibility limitations imposed by the designs and the short times available to perform the evaluations on the operational system. Test activity will include direct coupon evaluations as well as technique application evaluations throughout the development and verification test programs. Testing will be conducted by MDAC. The establishment of reliable NDE methods for each system sensitivity is necessary prior to the definition of system maintenance plans.

O. Coatings/Finishes Testing - The purpose of these tests is to evaluate the applicability of coatings or surface finishes to their Shuttle design application requirements. Systems requiring development include joint electrical bond coatings, corrosion resistant coatings, anti-seize coatings, lubrication, cabin interior finish selection, and thermal control coatings. Environmental compatibility and long term exposure tests will be performed on representative applications to establish acceptability for design. Testing will be conducted by MDAC. Each coating system must be satisfactorily developed or demonstrated to be applicable and acceptable for each design requirement.

P. Door Seal/Sill Development Tests - The objective of this test is to develop and verify a design concept for the sealing of mold line doors that will restrict the ingress of hot gasses into cavities that have to be maintained at relatively low temperatures and demonstrate reusability. The reason for this test is to establish feasibility of the concept and confidence that the design will survive the mission gas dynamics environments. This testing will be a logical follow-on to the door seal tests conducted during the Phase B supplemental test program. Specimens approximately 8" x 8" incorporating TPS, door and sill structure plus approximately 8" x 8" of fixed TPS will be evaluated. The test specimens will be exposed to plasma flow in two directions, flow parallel to door/sill joint and flow normal to door/sill joint. Ten tests in each direction will be performed. Flow impingement angle will simulate windward angle-of-attack during entry. To avoid unrealistic damage to interior structure, plasma heating will be stopped if the temperature of the interior becomes excessive. Test data will include temperatures and leakage rates as well as pre and post test photographs. Tests will be conducted in the MDAC and NASA-MSC gas dynamics test facilities. Test results are required prior to design of vehicle windward door seals.

Q. Large Scale Tankage Life Cycle Tests - The objective of this test is to evaluate and demonstrate the feasibility of assuring adequate life of main propellant tanks on the basis of NDE and proof testing.

The practicality of depending upon NDE as the prime method of detecting flaws in main cryo propellant tanks has been questioned in view of the size of the tanks. Evaluation of NDE techniques as a reliable approach requires demonstration on a "large" pressure vessel.

Test specimen will be approximately 8 ft. in diameter and 16 ft. long with integral stiffening simulating average requirements of the main fuel tank.

Tank will be subjected to material inspection, and inspection at several stages of manufacture, before and after proof pressure tests and at "operational intervals" representative of planned Shuttle fracture control procedures.

After post-proof test inspection, tank will be subjected to pressure cycling at operating stress levels. Complete internal and external inspections will be performed at intervals to be determined.

Cycling will continue until flaws (fatigue cracks) are detected by inspection. Crack growth may be observed for subsequent cycling; however, repairs will be made before failure and testing will continue to verify adequacy of repair and to evaluate ability of NDE to adequately detect flaw growth (if any) in the repair area. Test efforts will be integrated with NDE Development tests programs described in subparagraph N above.

Test cycling will continue for 500 cycles beyond repair of the third crack.

Test data will include NDE data, pressures; strains; details of flaw recognition, growth, and repair; pertinent photographs; and metallurgical evaluations of fractures. Tests will be conducted in MDAC-West Laboratories. Test results are required for at least 2000 cycles prior to tank structural sizing. This test potentially may be combined with Fuel Tank - Insulation Reusability Tests (Subparagraph A. above) if timeline sensitivities can be met.

R. Landing Gear (Main and Nose) Development Tests - The purpose of these tests is to perform final development of the landing gear metering pin systems so that design load-stroke profiles are attained. Tests will be conducted on the first gear assembly using analytically derived metering system for initial tests. Tests will be performed in a jig drop tower. Test data will include loads, strains, strut pressures, accelerations and motion pictures. Tests will be performed by or subcontracted by the landing gear vendor with MDAC cognizance. Testing and metering system development must be completed prior to production design release.

S. Cold Gas Jet Acoustic Test - The objective of this test is to define the near-field acoustic levels resulting from ABE operation during flight and horizontal ground takeoff.

Engine exhaust flow mixing and ground reflection will produce near-field acoustic levels of sufficient magnitude to influence the design of local structure. Since methods of predicting near-field acoustic levels for jet engine operation are virtually non-existent, model tests to provide measured data early in the design phase are required.

A 10% scale rigid model of the booster with cold gas jets scaled to simulate all ABE exhaust parameters except temperature will be used. Primary consideration is given to use of the appropriate wind tunnel model with configuration modifications to allow for producing the fluctuating pressure environments for both flight and ground operation of ABE's.

Wideband fluctuating pressure data will be obtained for the test conditions noted above. Data shall be taken at a sufficient number of points to define the near-field acoustic levels. RMS overall sound pressure levels and spectral plots will be determined for each data point. Tests will be conducted by MDAC. Test results are required during final structural design.

T. <u>Fluid - Elastic Structure Interaction Test</u> - Tests will be conducted to verify the fluid-elastic structure analytical model used for simulation of lateral and vertical motion of fluid in tanks. The presence of an elastic tank affects the fluid motion and may cause unacceptable amplification levels. For the Shuttle configurations, the thrust axis is at an angle to the tank centerline, hence coupling exists between vertical and lateral fluid motions. This coupling has to be analytically modeled and the analytical model verified by test.

A scale model of the booster LOX tank with sufficient section of LOX feedline incorporated will be tested to study fluid motion at feedline outlet. The tank scale will be the same as for Mated Vehicle model tests (Section 5.2) so multiple model utilization can be made. The test system will be sized to allow for large amplitude motion input to the tank for an arbitrary direction of force input.

Test data will include accelerations, forces, velocities, and displacements. Testing will generate fluid forces data and dry tank modal data. Testing will be conducted at MDAC and/or MSFC dynamics test facilities. The test data must be available prior to final design of tank baffles and POGO suppression devices.

5.1.7 Verification Tests - Airframe verification tests will be performed to demonstrate compliance with requirements and provide authentication of analytical characterizations or performance predictions. Airframe verification is, in total, a summation of all applicable development test data correlations, detailed and sophisticated analyses, and necessary testing required to demonstrate that design objectives have been met. Airframe verification testing includes subassembly acceptance testing, ground test programs, pre-flight acceptance tests and flight test demonstrations. The requirements to be fulfilled by airframe verification testing are reflected in Figure 5.1-12 and the major airframe verification tests are summarized in Figure 5.1-13.

AIRFRAME GROUP TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
(a) General	
(1) The airframe group systems shall be verified to be structurally adequate and functionally operable (as applicable) while subjected to the combinations of loads and natural and induced environments, based on the structural design criteria, which established the structural design requirements of the system.	Necessary to verify adequacy of design.
(2) Test articles shall be selected and test conditions imposed which fulfill the greatest range of technical requirements using the minimum amount of test hardware. The sensitivities of design, strength, thermodynamics, structural dynamics, propulsion and loads technologies shall be integrated in defining the test program, consistent with facilities capabilities.	Necessary to economy of program.
(b) Structure System	
(1) The structural verification test program shall be scoped and programmed to provide test data in consonance with program milestones while using less than an entire airframe for dedicated structural test purposes.	Necessary for test program economy.
(2) The test program shall include, as applicable, integrated method of obtaining test data related to influence coefficients, dynamic response (low level modal response, acoustic response and POGO), safe life, ultimate strength, thermal effects, and vibro-acoustic effects.	Necessary for efficient hardware utilization.

FIGURE 5.1-12

AIRFRAME GROUP TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
(3) Test hardware shall not, in general, be tested to failure to determine a design margin.	Necessary for effective utilization of test hardware. Ultimate strength demonstration will adequately verify the design strength.
(c) <u>Landing System</u>	
(1) The energy absorption characteristics of the landing gear systems shall be established and their ultimate strength verified. Environmental synergisms related to heating and exposure to reduced atmospheric pressure shall be considered in establishing test conditions.	Necessary to verify landing gear system compatibility.
(2) Vehicle deceleration devices shall be tested to verify deployment, response and adequacy under induced loads.	Necessary to substantiate design.
(d) <u>Thermal Protection System (TPS)</u>	
(1) The TPS shall be tested to verify adequacy for natural and induced environment design requirements. Special attention shall be given to panel dynamics (including acoustic response), heat transfer, and the synergistic effects of combined environments which may preclude dissociation of test environments.	Necessary to substantiate TPS design.
(2) TPS designs of material applications that are adequately similar between booster and orbiter vehicles shall be tested only to the most critical environments of either vehicle.	Duplication of test eliminated for economy.

FIGURE 5.1-12 (Cont.)

MAJOR STRUCTURAL TESTS – CANARD BOOSTER

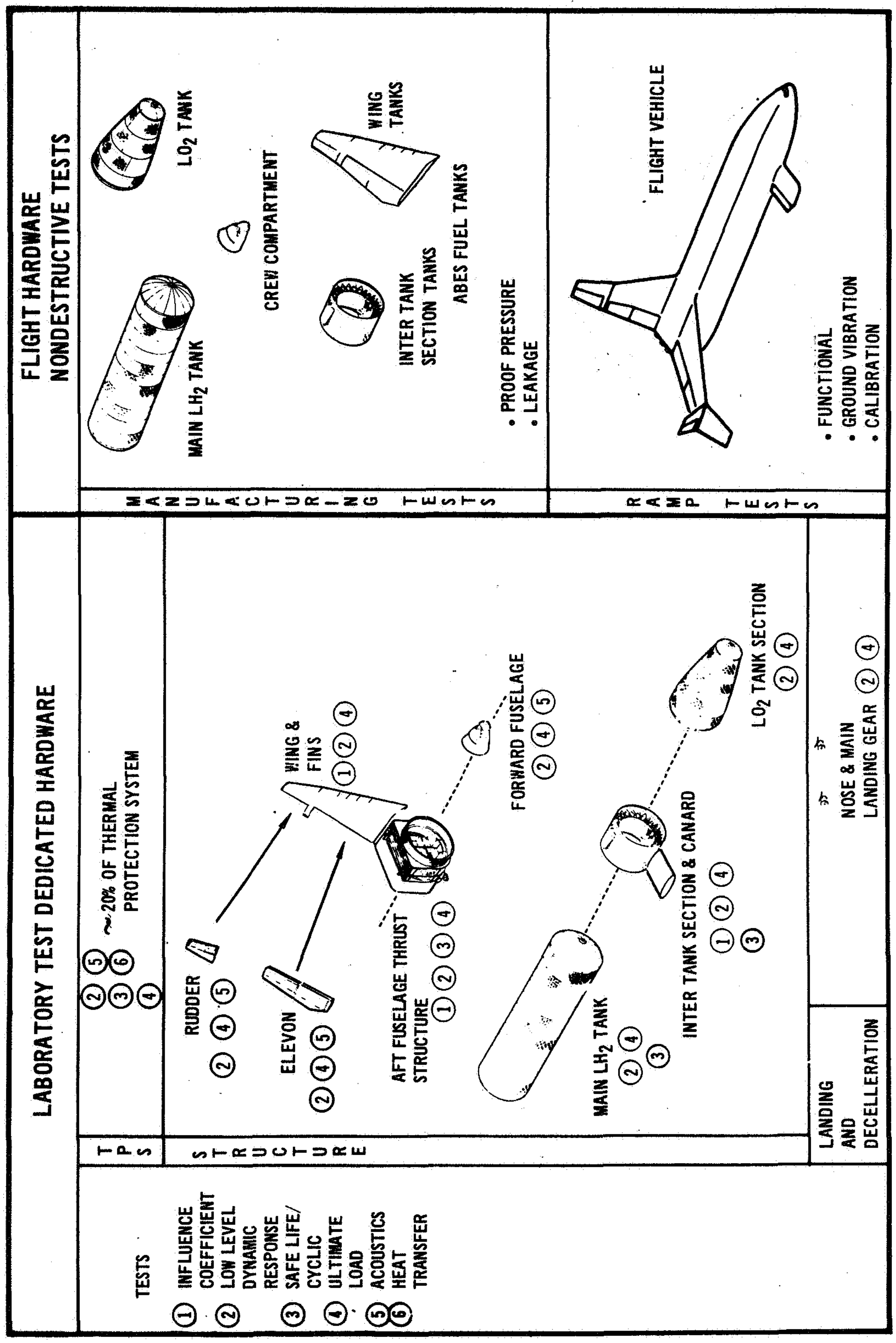


FIGURE 5.1-13

5.1.7.1 Subassembly Acceptance Tests - Tests will be performed on subassemblies during the manufacturing phase to verify proper assembly and that integrity, operation and performance are within design specifications. Examples of subassemblies and of how they are tested are as follows:

Cabling - Continuity, insulation breakdown, shielding and grounding tests will be performed.

Fluid Lines, Manifolds - Fabricated lines will be hydrostatically proof pressure tested. Jacketed cryogenic lines will be cold shocked using a cryogenic fluid and leak tested using a mass spectrometer.

Tanks - All pressure vessels will be proof pressure tested during their manufacture. The main propulsion LH_2 tank is manufactured and assembled in sections. Upon final assembly, a pneumostatic proof pressure test is performed to validate the assembly. The main propulsion LO_2 tank is tested in two sections using a hydrostatic/pneumostatic method. The aft section is hydrostatically tested then joined with the forward section for overall pneumostatic test. Other tanks will be tested by applicable hydrostatic or pneumostatic methods.

Modules - Applicable cabling, line, and tank tests, as above, will be performed on modules during and/or after manufacturing build-up. Modules tested will vary from relatively small pneumatic units to major assemblies consisting of a complete cabin-nose section. Module testing is designed so that upon final assembly there will be no requirements to repeat the tests to the same level. Next assembly testing is to be mainly concerned with validation of interfaces. Tests of modularized components will be deferred until the subsystem is completed on the next assembly for cases where complex and expensive simulators are required to accomplish the test in a module level.

5.1.7.2 Airframe Verification Ground Tests - The basic approach toward preflight verification of the structural adequacy of the vehicle, satisfying the requirements of Figure 5.1-12 is by selecting critical sections for rigorous ground testing. This approach was selected for the following reasons:

(a) Different areas or sections of the vehicle have different structural criticalities. Test conditions are therefore encountered on an assembled airframe which necessitates end-to-end testing and/or partial airframe disassembly. This has the undesirable effect of lengthening the total testing period.

(b) Demonstration of the ultimate strength of various vehicle sections having different test requirements would require scoping the test system to accommodate the total airframe, whereas section testing allows use of smaller scale test capabilities.

(c) Sectionalized testing allows overall program progress even if individual tests disclose structural anomalies on a single component. With total airframe testing, an anomaly discovered during test portends a delay of the entire test program while local problems are resolved. It is doubtful that scheduled test of a major section or zone on an assembled airframe could be implemented in parallel with unanticipated development tests on another part of the airframe, either from a technical or safety aspect. Furthermore, a catastrophic failure on an assembled airframe jeopardizes the availability of subsequent test hardware.

(d) The sectionalized approach allows testing to be disseminated to coincide with design or manufacturing locations or to a facility where testing capability already exists.

(e) Verification testing of major sections can start up to five months earlier than possible if airframe assembly were required. Ground test data will therefore be available during flight vehicle buildup.

In synthesizing the airframe verification ground test program the following technical/technology philosophies or approaches have been applied.

- Fatigue testing per se is not anticipated on the Space Shuttle vehicles. Safe life demonstrations will be performed on critical hardware. This hardware will have been designed to safe life criteria and be classified as Criticality I.

Rationale - The relatively short operating cycle life of the vehicle (as compared to aircraft) does not portend major overall structural fatigue problems in consideration of vehicle design and aircraft technology.

- The approach to structural dynamics testing is to integrate structural dynamics test requirements with the major structural section tests, the propulsion integration tests (Section B 6.4), a mated vehicle scale model test (Section A 6.2), and low level nondestructive dynamic response tests on the assembled flight vehicle (Sections A 7.3, B 7.2, and C 7.2). The integration of structural dynamics tests will be implemented in sequences and by methods which do not jeopardize the validity of subsequent tests or the integrity of the flight destined hardware.

The selection of the structural sections to be tested and their individual sensitivities are designated by the analytical technologies. Through test requirements integration and iterative coordination between the various technologies, a final selection of test hardware (single test articles unless otherwise noted) and test conditions has been made. The ground development and verification test requirements recognized, the preliminary test approaches and implementation plans for the testing of the airframe are presented in the following subparagraphs. A subparagraph titular summary is presented here for convenience.

A. Forward Fuselage Tests

B. LO_2 Tank Section Tests

C. Intertank Section and Canard Tests

D. Main LH_2 Tank Tests

E. Fin - Rudder Tests

F. Landing Gear Tests (Nose and Main)

G. Wing - Aft Fuselage Tests

H. Elevon Tests

I. Thermal Protection System Tests

J. ABES Fuel Tank Tests

Related scheduling of the above tests is shown in Figure 5.1-14.

A. Forward Fuselage - The objectives of this test are to demonstrate the structural adequacy, determine acoustic transfer functions, and determine dynamic characteristics of the forward fuselage section. The test article will be the primary structure of the forward fuselage assembly (Stations X1030 to X1235). The test section will be jig mounted and the following tests performed:

Low Level Dynamic Response

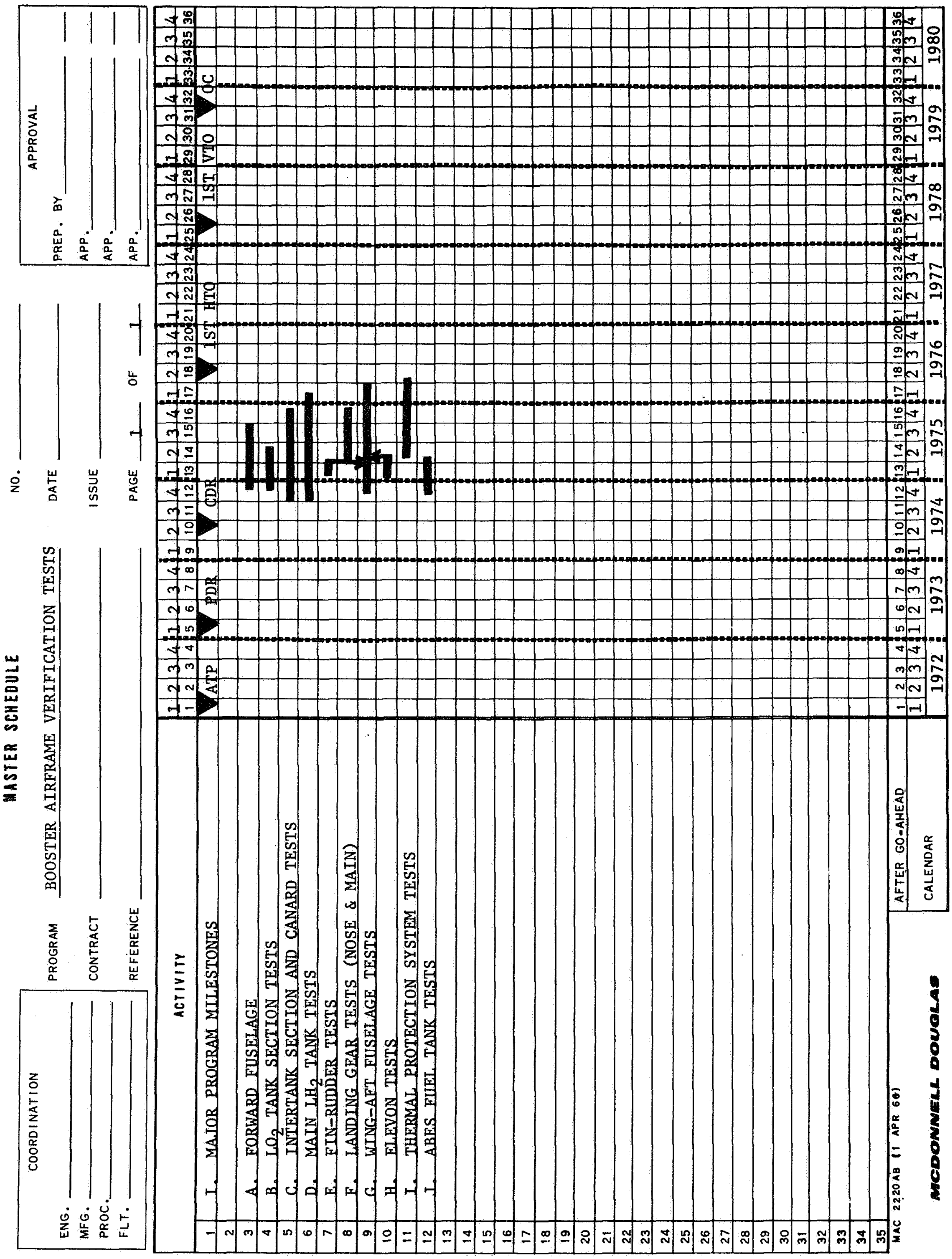
ACPS Thruster Influence Coefficient

Structural Loads (Limit)

Vibro-Acoustic Test

Ultimate Pressure in Crew Compartment

Test data will include dynamic modal data, loads, pressure, deflections, strains, acoustic data and photographs. Static tests will be conducted by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FLT.
ACTIVITY
I. MAJOR PROGRAM MILESTONES
A. FORWARD FUSELAGE
B. LO2 TANK SECTION TESTS
C. INTERTANK SECTION AND CANARD TESTS
D. MAIN LH2 TANK TESTS
E. FIN-RUDDER TESTS
F. LANDING GEAR TESTS (NOSE & MAIN)
G. WING-AFT FUSELAGE TESTS
H. ELEVON TESTS
I. THERMAL PROTECTION SYSTEM TESTS
J. ABES FUEL TANK TESTS
ATP
PDR
CDR
1ST HTO
1ST VTO
OC
AFTER GO-AHEAD
CALENDAR
1972
1973
1974
1975
1976
1977
1978
1979
1980
MAC 2220AB (1 APR 66)
McDONNELL DOUGLAS

FIGURE 5.1-14

MDAC-EAST in MDAC Structures Laboratories and the NASA-MSC Spacecraft Acoustic Laboratory. Structural testing to limit loads is required prior to HTO, with dynamics, acoustics, and ultimate cabin pressure testing completed prior to VTO.

B. LO_2 Tank Section Tests – The objectives of these tests are to establish the dynamic characteristics of the LO_2 tank section and Fluid-Structure coupling modes and to demonstrate the structural adequacy of the LO_2 tank. The test article will be the LO_2 tank section of the vehicle which extends from X1235 to X1883 splice rings. The test section will be supported by adapter rings simulating the splice ring interface joints. Testing will include low level dynamic response determinations performed with the tank empty and with various liquid (water) fill levels. Following modal response testing the tank will be subjected to ultimate internal pressure loads. (The LO_2 tank is structurally sensitive only to internal pressure conditions.) Test data will include dynamic modal data, strains, deflections, pressures, and photographs. Testing will be performed by MDAC-West in the Michoud Hydrostatic Test Facility. Dynamic test results are required prior to POGO suppression system final design and structural test results are required prior to VTO.

C. Intertank Section and Canard Tests – The objective of these tests is to demonstrate the structural adequacy of the intertank structure and canard. The test article will consist of the primary structure of the intertank section (X1883 to X2163) and one canard structure. The test article will be mated to test structure at the interface splices using test adapters to simulate attachments to the LO_2 and LH_2 tank sections. The test program will include the following tests:

Low Level Dynamic Response

Nose Landing Gear Backup Structure Tests

Canard Influence Coefficients

Forward Vehicle Interconnect Backup Structure Safe-Life Tests

Canard Aerodynamic and ABE Loads and Forward Door and Jet Flap Loads/ Compatibility

ABE Door Compatibility

Nose Landing Gear Door Tests

Intertank Structural Loads (Axial Loads and Equipment Loads)

Test data will include dynamics modal data, loads, strains, deflections, and photographs. Tests will be conducted by MDAC-West in the NASA-MSFC Building 4619 Load Test annex. Test results are required prior to HTO.

D. Main LH_2 Tank Tests - The objective of these tests is to demonstrate the structural dynamics characteristics and the structural adequacy of the main LH_2 tank. The test article will consist of the uninsulated main LH_2 tank with wing leading edge attachment and aft vehicle interconnect attachment. The test section will encompass the zone from station X2163 to to X3553 splice joints. The tank will be supported by test fixtures which simulate the splice joint interfaces. The following tests will be performed:

Low Level Dynamic Response

Safe Life Testing of Aft Vehicle Interconnect Structural Support

Maximum Axial Loads Tests

Ultimate Internal Pressure Tests

Test data will include dynamics modal data, loads, strains, deflections, and photographs. Tests will be conducted by MDAC-West using the

NASA-MSFC Building 4557 Dynamic Test Stand utilized as a structural test base. Testing must be completed prior to HTO.

E. Fin and Rudder Tests – The objective of these tests is to demonstrate that the structure is capable of sustaining critical combinations of loads and temperatures which occur during ascent and airplane flight. An additional objective is to verify the adequacy of the rudder and associated fin support structure for the desired operating life.

The test specimen is comprised of the fin and rudder primary structures including hinge and actuation fittings, leading edge segments and a rudder segment from the vicinity of the actuator drive rib.

The Fin-Rudders will be installed on the test wing of G below. The rudder segment will be jig mounted to provide test specimen support and boundary condition regulation.

The Fins and Rudders will be subjected to the following tests:

Low Level Dynamic Response

Maximum Side Load

Maximum Rudder Load

Ascent Maximum βq

Leading Edge Compatibility

The rudder segment will demonstrate safe life adequacy in the structural, thermal, and acoustic environments. Test data will include loads, strains, deflections, dynamic modes/frequencies, acoustic levels, and photographs. Full system tests will be conducted in the MMC-Baltimore Structures Laboratories. Element tests will be conducted by MDAC-West. The dynamic response, side and rudder loads, and leading edge tests must

must be completed prior to HTO, the ascent βq and 20 percent of safe life tests must be completed prior to VTO, and safe life tests must be completed prior to O.C.

F. Landing Gear Tests (Nose and Main) - The objective of these tests is to demonstrate that the main and nose landing gear structures are capable of sustaining critical combinations of load and temperature associated with landing, taxiing, and turning.

The test specimens are a nose gear primary structure, support fittings and mechanisms complete with actuators and a main landing gear structure, support fittings and mechanisms complete with actuators for the LH system.

The test gear assemblies will be individually mounted and the following tests performed:

Jig Drop Tests: Springback and Reserve Energy

Dynamometer Shimmy Test (Nose Gear)

Braked Roll Loads Tests

Turning Loads Tests (Main Gear)

Deployment Function Demonstrations

Test data will include load-stroke curves, loads, deflections, strains, dynamic modes and frequencies (nose), and photographs. Jig drop tests will be performed by the gear vendor(s), dynamometer tests will be performed on the WPAFB high speed dynamometer, and static tests will be performed in MDAC Structures Laboratories; all testing must be completed prior to HTO.

G. Wing - Aft Fuselage Tests - The objective of these tests is to demonstrate that the structure is capable of sustaining critical combinations of loads and temperatures associated with maximum αq, maximum βq, maximum axial load and engine ignition occurring during ascent, maneuver, and landing.

The test specimen is the primary structure aft of X3553 and is comprised of an aft tank skirt, thrust structure, L.H. wing and wing carry through, landing gear doors, elevon (from H below), and fin-rudders (see subparagraph E above).

The test section will be jig mounted with its longitudinal axis horizontal with test fixturing supplying test section support and boundary condition control. The following tests will be performed:

Low Level Dynamic Response

Influence Coefficients: Wing Thruster and Main Engine Thrust Structure

Main Landing Gear Backup Structure Tests

Wing/Elevon Loading Tests

Landing Gear and Door Tests

Aft Fuselage Bending Tests

Main Engine Loads Tests

Thrust Structure Safe Life Tests

Wing Fuel Tank Pressure Loads

Test Data will include loads, strains, deflections, velocities, accelerations, and photographs. The tests will be performed by MDAC-West in the MMC-Baltimore Structural Test Facility. Dynamic response, Wing, Elevon, Fin-Rudder, and Landing Gear Backup Structure, and Doors tests must be completed prior to HTO. Fuselage bending, 20 percent of safe life, and Main Engine loads tests must be completed prior to VTO. Safe life tests must be complete prior to O.C.

H. Elevon Tests – The objective of these tests is to demonstrate that the structure is capable of sustaining critical combinations of loads and temperatures associated with entry maneuver and during the airplane flight phase and to verify the adequacy for the desired operating life.

Test Specimen Description - The test specimen is the L/H elevon primary structure complete with hinge and actuation fitting; the specimen for the life test will be a section of the elevon surrounding the actuation rib.

The test elevon will be mounted on the wing of the wing-aft fuselage test section described in G above. The elevon section tests will be jig mounted to provide test specimen support and boundary condition regulation.

The elevon will be subjected to the following tests in conjunction with wing loading tests:

Low/Level Dynamic Response

Maximum $+\dot{q}$

Maximum $-\dot{q}$

Wing Compatibility Demonstration

The elevon section will be used to demonstrate safe life adequacy for thermal, acoustic, and structural loadings. Test data will include loads, strains, deflections, velocities, accelerations, acoustic levels, temperatures, and photographs. The elevon will be tested in conjunction with wing tests at MMC-Baltimore Structural Test Facility. Elevon section tests will be accomplished in MDAC Thermal/Structural Test Laboratories. The wing compatibility, Maximum $-\dot{q}$, and elevon dynamics tests must be completed prior to HTO; Maximum $+\dot{q}$ and 20 percent of safe life tests must be complete prior to VTO; and safe life demonstrations must be completed before O.C.

I. Thermal Protection System Tests - The objective of these tests is to demonstrate structural capability of the test articles and that structural design goals have been achieved. The TPS heat shield panels and related support structure must demonstrate reuse capability for simulated environment missions including loads, temperatures, and acoustic excitation from lift off, ascent maximum αq, ascent shock interference, ascent vent lag pressure, entry condition, airplane cruise phase, landing and ground operations.

The test specimens are comprised of TPS heat shield panels, transverse support beams, panel retainers, support struts, and drag links. The test specimens will consist of pairs of TPS panels with a transverse joint between them. It is anticipated that approximately 20% of the TPS will be evaluated.

The test specimens will be subjected to low level dynamic response tests to determine panel modes and frequencies. The panels will then be subjected to repeated exposures simulating the conditions of acoustic environments and flight absolute pressures and pressure differentials with heat.

Test data will include pressures, acoustic levels, strains, deflections, temperatures, panel dynamic response, and photographs.

Test results will be used to verify the analytical predictions and correlate results from design-development tests. Tests will be conducted in MDAC Thermal-Structural and Acoustic Test Laboratories. All testing must be completed prior to O.C. with adequate testing completed to assure flight safety prior to HTO and VTO flights.

J. <u>ABES Fuel Tank Tests</u> – The objective of these tests is to establish the dynamics characteristics and the structural adequacy of the ABES fuel tank.

The test article will be a single ABES fuel tank with its supporting fittings. The tank will be mounted in a test jig and the following tests performed:

Low Level Dynamic Response

Acceleration Loads

Pressure Loads

Test data will include dynamics data, loads, strains, deflections, pressure, and photographs. Tests will be conducted in MDAC Structural Test Facilities. Test results are required prior to HTO.

5.1.7.3 Preflight Acceptance Tests - Airframe Structure/Mechanical

Landing Subsystems - Gear extension and operations are verified using both primary and redundant modes of actuation. To exercise backup modes, GSE is used to simulate failures of the primary systems.

Mechanical - Mechanical subsystems - separation and aerodynamic control surfaces - will be cycled through their operating modes. Fit, alignment, and functional checks will be performed. External GSE will be used to support these tests. Redundant operating modes of the separation subsystems will be checked by the DMS and GSE simulators.

5.1.7.4 Flight Test Demonstrations

Structures - Structural and flight loads testing of the booster in the subsonic flight regime will be similar to current large airplane testing. However, the program will be reduced in scope, since many of the flight design conditions occur during ascent and entry mission phases. Strain gage instrumentation for the measurement of horizontal flight loads will be calibrated by ground loads application prior to flight. Due to schedule constraints, boosters S/N 2 and 3 will also be instrumented for the measurement of flight loads, to acquire ascent and entry loads data. Flight loads data will be obtained during a series of flight maneuvers throughout the booster airplane flight envelope, building up to the most critical test conditions. The maneuvers will include symmetrical pull-ups and push-overs, rolling pull-outs, steady sideslips, rudder kicks, and both clean and approach configuration maximum velocity conditions. The loads data will be analyzed, extrapolated, and compared to predicted values to verify the adequacy of the design loads and structural margins. Sufficient testing to establish a high degree of confidence in the design margins associated with the cruiseback and landing flight envelope will be completed prior to first manned orbital flight.

The absence of aerodynamic flutter and the acceptability of aero-elastic structural response during cruise flight and landing will be verified concurrently with other flight objectives, such as the preliminary evaluation and structural flight load testing. Specific flutter testing utilizing exciter systems is not planned, since the design flutter flight conditions will occur during ascent at Mach No./dynamic pressure conditions well beyond those attainable in airplane flight.

The structural vibration and acoustic environment levels will be measured during takeoff, landing, and most critical airplane flight conditions to verify design levels. Pressure data will be obtained for selected internal areas for venting analyses. This testing will be concurrent with other horizontal flight tests.

The vertical flight test program will be planned to progress in a buildup manner from less critical to nominal flight conditions. Trajectory and mission planning techniques will be employed to keep the structural loads, entry heating, and attitude control limits well within the booster design limits. Incremental increases in severity will be employed in subsequent flights.

The vertical flight test booster (S/N 3) will be extensively instrumented with strain gages, accelerometers, pressure transducers, thermocouples, etc., for the measurement of structural loads and environment during launch, ascent, and entry. Strain gage location and calibration loading techniques will be the same as in the first horizontal flight test booster (S/N 1) whenever possible. The loads data will be analyzed and extrapolated, and compared to predicted values to verify the adequacy of the design loads and structural margins. Specific consideration will be given to verifying that the actual longitudinal loads, bending moments, and wing shear loads are within the vehicle capability.

Ignition and ascent vibration and acoustic environments will be monitored to verify that there is no structural damage potential inherent in the coupling between the propellant feed systems and structural oscillations (POGO). Base heating and base pressure environments will be verified. Venting characteristics for nonpressure-vessel compartments will also be verified. In addition, the absence of aerodynamic flutter and the acceptability of aeroelastic structural response during ascent, entry, and transition will be verified.

The functional mechanical operation of control surfaces, flaps, protective doors and shrouds, landing gear extension, etc., in their most critical flight environments during ascent, entry, and cruiseback and landing will be verified concurrently during the normal course of the vertical and horizontal flight test programs. The absence of undesirable effects due to actual and previous mission environmental conditions will be verified.

<u>Landing and Deceleration</u> - The brief preflight taxi evaluation of landing gear functional operation is described above. Further dedicated testing will be required to develop and verify the performance of the wheels, brakes, and antiskid system and the overall strength and adequacy of the landing gear and their backup structure. The necessary data will be obtained during the test hours allocated to

takeoff and landing performance and the automatic landing system, in addition to the dedicated flight hours listed in Paragraph 7.4. Landing gear and structural loads data will be obtained during taxi, braking, and actual landing conditions, to verify structural adequacy. This testing will be completed prior to the first manned orbital flight. Satisfactory functional operation of the wheels, brakes, and antiskid subsystems, after exposure to the vibration, airload, and heat environments imposed by vertical operations, will be demonstrated. Data will be correlated with horizontal flight test results for verification purposes.

Thermal Protection System - The thermal environment imposed by the air-breathing engines and the auxiliary power units (APU) and their exhausts on adjacent structures at various power settings during takeoff, landing, and airplane flight will be measured concurrently with other horizontal flight test objectives. This data will be utilized to verify the adequacy of the thermal protection system in those areas.

A large number of temperature sensors will be installed to measure external and internal structural temperatures during launch, ascent, and entry. This data will be correlated with wind tunnel data and design analyses to verify the correctness of the predicted aerothermodynamic flow effects and the resulting thermal environments, and the adequacy of the thermal protection system. Trajectory shaping of the initial flight profile to experience less-than-nominal temperature conditions is planned. Should this prove impracticable, the installation of additional thermal protection on the flight test booster (S/N 3) to protect against unpredicted heating distributions and local hot spots, will be considered. Once sufficient confidence in the temperature distribution is attained, subsequent flights will increase the aeroheating levels to nominal conditions.

The effects on adjacent structure of the imposition of launch, ascent, and entry heat loads in addition to the thermal loads of the airbreathing engines and auxiliary power units will be evaluated during the cruiseback and landing phase of vertical flights.

5.2 Propulsion Group - The Booster propulsion group is comprised of the main propulsion system, the attitude control propulsion system, the airbreathing engine system and the auxiliary power systems. A summary chart depicting the interrelationship between these systems tests is presented in Figure 5.2-1.

5.2.1 Booster Main Propulsion System

5.2.1.1 Booster Main Propulsion System Description - The main propulsion system is made up of engines, propellant tanks, lines, valves, and miscellaneous hardware to provide the Booster main impulsive energy. The main engines will be high pressure LOX/LH_2 engines which will be GFE equipment. The main engine propellants are stored in propellant tanks with independent ground prepressurization and engine-bled flight pressurant gases. The propellant masses are burned at a constant engine mixture ratio. Residuals are minimized by appropriate loading techniques. Each engine is fed by an independent LH_2 feed line. Six (6) engines are supplied by a single, branched LOX downcomer feed line. Propellants are controlled by fill, drain, vent and relief valves as appropriate. Valve actuation control and low volume purges are provided by a regulated pressure helium control pneumatic system. The gas storage for the stage pneumatic system is common for another regulated helium supply system which supplies the engines with purge gases. A schematic of the main propulsion system is presented in Figure 5.2-2. A schedule of the main propulsion system tests in presented in Figure 5.2-3.

5.2.1.2 Test Requirements and Justification - Booster main propulsion system test requirements and justification are presented in Figure 5.2-4.

5.2.1.3 Test Approach and Rationale

5.2.1.3.1 Special Engine Manufacturer Tests

Test Hardware: The following hardware will be made available to the engine manufacturer as soon as the first production hardware can be made available. 1) Hydraulic actuators; 2) POGO suppression accumulators; 3) Bleed pressurization

BOOSTER PROPULSION TESTING

TESTS	REQUIREMENTS AND OBJECTIVES	APPLICABILITY		HARDWARE		FACILITY AND SET-UP
		COMMON	BOOSTER ONLY	QUANTITY	TYPE	
CRYOGENIC TANK INSULATION DEVELOPMENT (INTERNAL AND EXTERNAL)	MAIN PROPULSION LH_2 AND ACPS TANK INSULATION DEVELOPMENT, REUSABILITY AND HIGH TEMPERATURE BONDING DEVELOPMENT	X	X	ONE SCALE TANK	SMALL SCALE. NOT PRODUCTION REPRESENTATIVE	CRYOGENIC FLOW TEST FACILITY. HYDROGEN LIQUIDS WITH GASEOUS PURGING CAPABILITY. SACRAMENTO TEST CENTER AND MSFC CONSIDERED.
LH_2 AND LOX RETENTION/EXPULSION DEVELOPMENT AND VERIFICATION	DEVELOPMENT OF RETENTION AND POSITIVE EXPULSION DEVICES FOR LOX AND LH_2 ACPS SUPPLY. DEMONSTRATE SYSTEM CAPABILITY INCLUDING ZERO G ENVIRONMENT	X		ONE DEVELOPMENT AND ONE LARGE SCALE PROTOTYPE TANK. RETENTION DEVICES FOR EACH FOR LOX & LH_2	DEVELOPMENT TANK NOT SCALE OF PRODUCTION. LARGE SCALE PROTOTYPE TO BE BOILERPLATE FULL SCALE OR NEARLY FULL SCALE REPRESENTATIVE OF PRODUCTION TANKS	LH_2 AND LOX FLOW TEST FACILITY INCLUDING PURGE AND CONTROL GASES, E.G., SACRAMENTO TEST CENTER, WHITE SANDS, MSFC. SMALL SCALE ZERO G TESTS IN KC-135 TYPE AIRCRAFT OR DROP TOWER.
INTEGRATION OF ATTITUDE CONTROL PROPULSION SYSTEM (ACPS)	DEVELOPMENT OF TOTAL ACPS WITH INTERRELATED SYSTEMS, E.G. AVIONICS (DIU TO ACPS EQUIPMENT), APU AND GSE	X	X	ONE SET	PROTOTYPE PRODUCTION	HYDROGEN AND OXYGEN LIQUID AND GAS SUPPLIES INCLUDING HELIUM AND NITROGEN. GROUND COMPUTER WITH INSTRUMENTATION RECORDING SYSTEM. TEST HARDWARE ARRANGED LIKE STAGE INSTALLATION WITH PROVISIONS TO TEST APU AS INTEGRAL PART OF TEST SETUP. SACRAMENTO TEST CENTER OR WHITE SANDS CONSIDERED.
INTEGRATION OF AUXILIARY POWER UNITS (APU'S)	DEVELOPMENT OF APU SYSTEM WITH INTERRELATED SYSTEMS, E.G. AVIONICS (DIU TO APU), ACPS, HYDRAULIC AND ELECTRICAL POWER, GSE AND ABES FUEL MANAGEMENT		X	ONE APU INCLUDING HYDRAULIC PUMPS AND ALTERNATOR	PROTOTYPE PRODUCTION	GASEOUS HYDROGEN, OXYGEN, HELIUM AND NITROGEN PLUS JP LIQUID SUPPLY. APU INSTALLATION IN BOOSTER PROTOTYPE ARRANGEMENT. SIMULTANEOUS INTEGRATION WITH ACPS DESIRABLE. SACRAMENTO TEST CENTER OR WHITE SANDS CONSIDERED.
BOOSTER COMPONENT TESTING AT MAIN ENGINE MANUFACTURER	INTEGRATION OF BOOSTER COMPONENTS WHICH INTERCONNECT WITH THE MAIN ENGINE. PROVIDES DATA USEFUL TO ENGINE AND STAGE MANUFACTURER.	X	X	ONE SET HYDRAULIC ACTUATORS, GH_2 AND GOX PRESSURIZATION CONTROLS, POGO SUPPRESSOR, AND HEAT SHIELD ATTACHMENTS	PROTOTYPE PRODUCTION	ENGINE MANUFACTURER TEST FACILITY.
PROPULSION INTEGRATION TESTING	DEVELOPMENT AND VERIFICATION OF PERFORMANCE AND INTERRELATIONSHIPS BETWEEN MAIN PROPULSION SYSTEM, APU, HYDRAULICS, ELECTRICAL POWER, ACPS, AVIONICS AND STRUCTURE SYSTEMS.		X	ONE FUSELAGE SET	PRODUCTION	UTILIZE FINAL LAUNCH SITE, KSC OPERATIONAL LAUNCH UMBILICAL TOWER (LUT), GSE AND FACILITY. MINOR MODIFICATION TO LUT HOLDDOWN ARMS FOR LONG DURATION FIRINGS.
FULL SCALE SINGLE AIRBREATHING ENGINE WIND TUNNEL ALTITUDE STARTING TESTS	DEVELOPMENT OF TECHNIQUE TO BE USED FOR REENTRY AIRSTART. EVALUATION OF WINDMILL, CARTRIDGE AND CROSS BLEED STARTING CHARACTERISTICS AT ALTITUDE		X	ONE AIRBREATHING ENGINE COMPARTMENT, INLET AND EXIT NOZZLE	PRODUCTION PROTOTYPE	AEDC 16T WIND TUNNEL.
AIRBREATHING ENGINE FUEL SUBSYSTEM DEVELOPMENT	DEVELOPMENT OF HORIZONTAL AND VERTICAL FUEL MANAGEMENT SUBSYSTEMS		X	ONE HALF SET (RIGHT OR LEFT SIDE)	BOILERPLATE TANKS - PROTOTYPE FUEL CONTROL, MEASUREMENT AND MONITORING SUBSYSTEMS	JP FUEL SUPPLY, HELIUM AND AIR TO PRESSURIZE TANKS. INSTRUMENTATION AND CONTROLS FOR FUEL MANAGEMENT SYSTEM.

FIGURE 5.2-1

BOOSTER PROPULSION TESTING

TESTS	REQUIREMENTS AND OBJECTIVES	APPLICABILITY		HARDWARE		FACILITY AND SET-UP
		COMMON	BOOSTER ONLY	QUANTITY	TYPE	
HORIZONTAL FLIGHT DEVELOPMENT	TOTAL AIRBREATHING ENGINE AND JP FUELED APU SYSTEMS VERIFICATION. HYDRAULICS SYSTEM VERIFICATION EXCEPT FOR MAIN ENGINE ACTUATORS		X	BOOSTER S/N 1	PRODUCTION	KSC-EDWARDS AIR FORCE BASE.
FLIGHT READINESS FIRINGS	MAJOR ACPS, APU, HYDRAULICS, ELECTRICAL POWER AVIONICS AND MAIN PROPULSION SYSTEMS VERIFICATION IN PREPARATION FOR FIRST VERTICAL FLIGHT		X	EACH BOOSTER	PRODUCTION	KSC OPERATIONAL LAUNCH SITE.
VERTICAL FLIGHT TEST	VERIFICATION AND DEMONSTRATION OF CAPABILITY OF ALL PROPULSION SUBSYSTEMS WITHIN CEI LIMITATIONS		X	BOOSTERS S/N 2 & 3	PRODUCTION	KSC OPERATIONAL LAUNCH SITE.

FIGURE 5.2-1 (Cont.)

BOOSTER MAIN PROPULSION SYSTEM

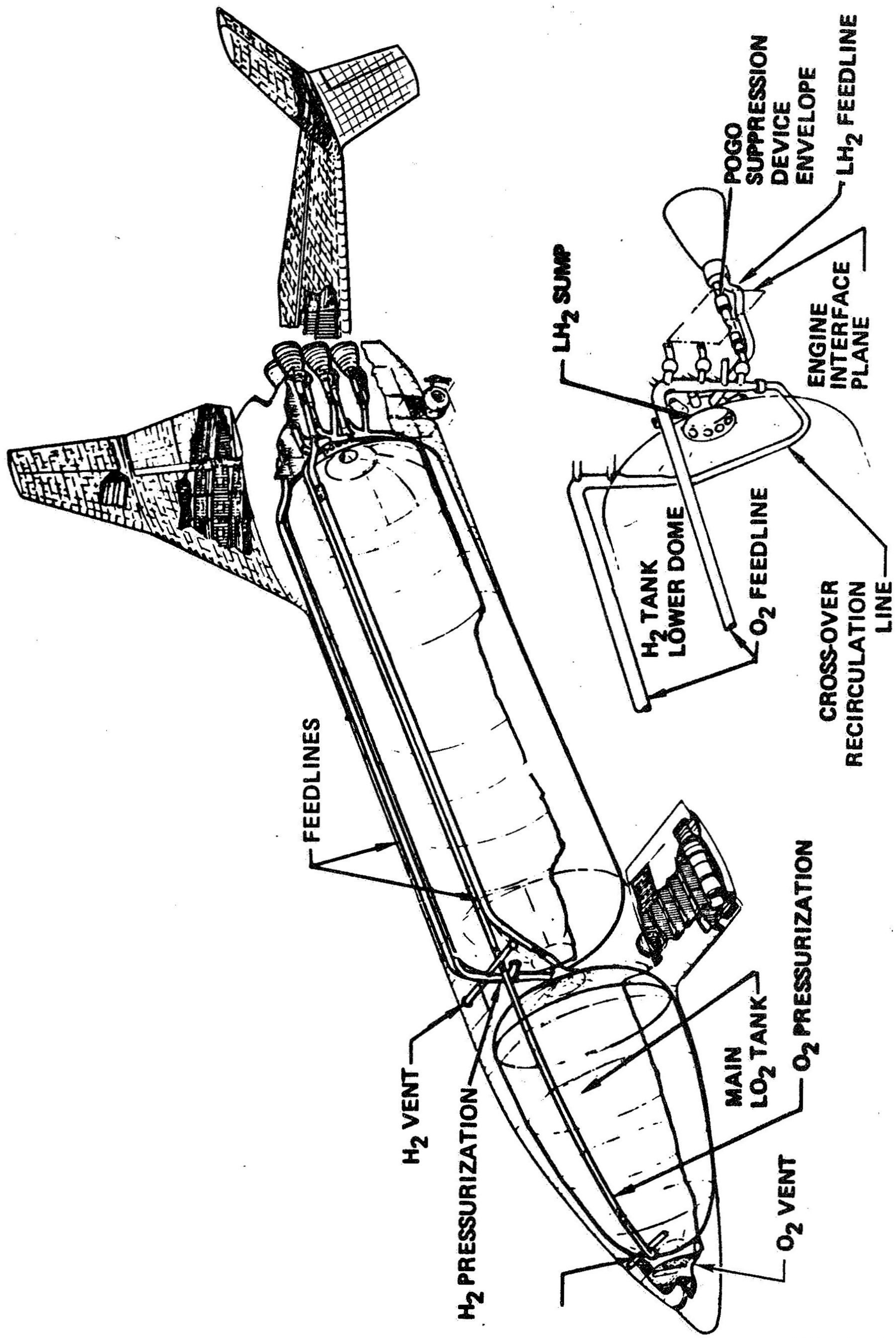

FIGURE 5.2–2

MASTER SCHEDULE

COORDINATION
ENG. ______
MFG. ______
PROC. ______
FLT. ______

PROGRAM BOOSTER MAIN PROPULSION SYSTEM TESTS
CONTRACT ______
REFERENCE ______

NO. ______
DATE ______
ISSUE ______
PAGE ______ OF ______

APPROVAL
PREP. BY ______
APP. ______
APP. ______
APP. ______

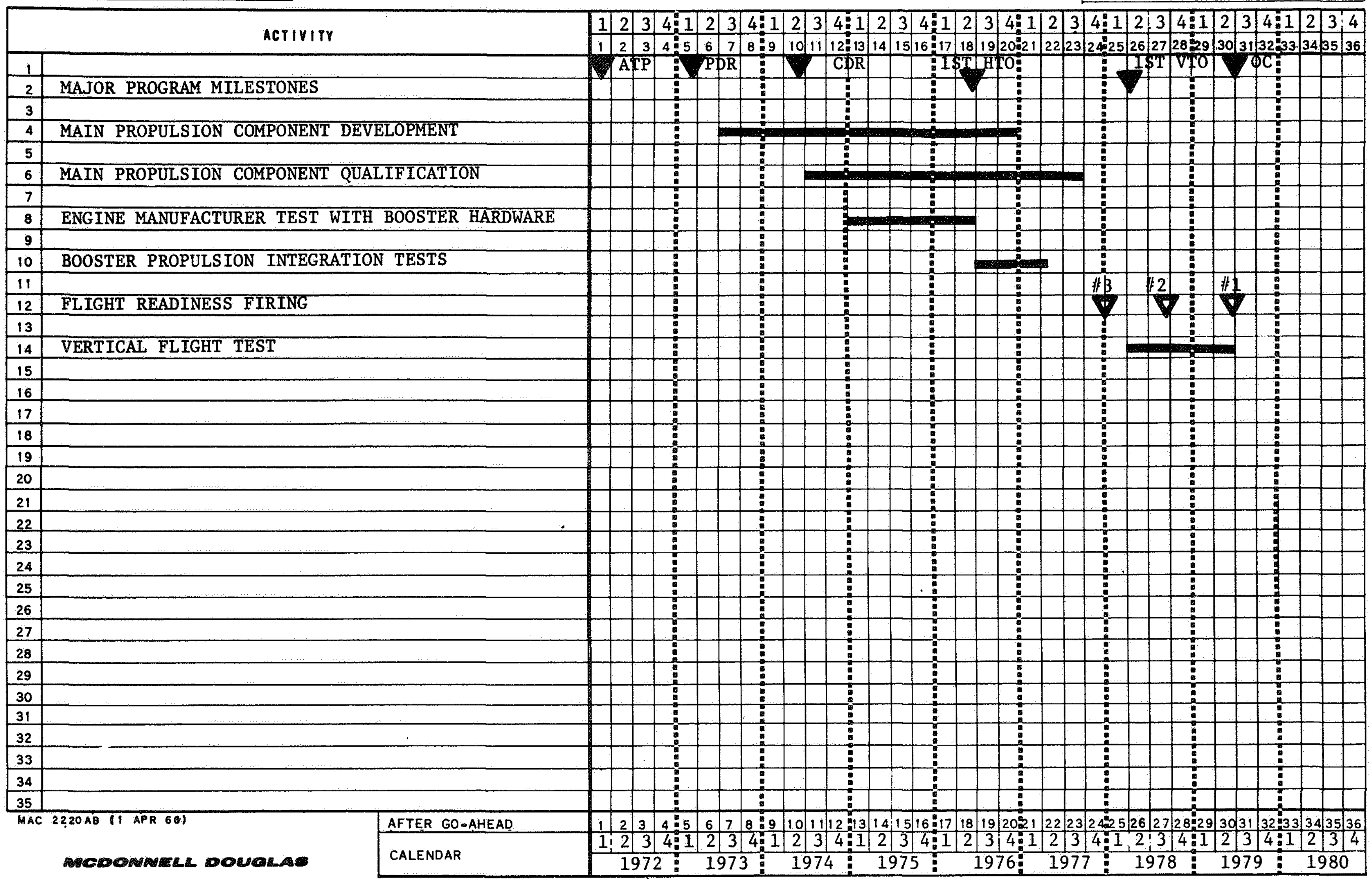

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FIGURE 5.2–3

MAIN PROPULSION SYSTEM TEST REQUIREMENTS

TEST REQUIREMENT	JUSTIFICATION
(1) Pneumatic Control - The ability of the pneumatic system to supply adequate pressure and flow at all times for vehicle systems component actuation control and purging and for engine control and purging (including redundancy mode capability) shall be demonstrated.	To provide assurance that the pneumatic system will perform acceptably during all conceived demand requirements.
(2) Main Propellant Tanks Pressurization and Vent - Ground controlled tank pressurization (during maintenance, checkout, propellant loading, prepressurization and purging) and flight controlled tank pressurization (boost flight, coast, reentry, cruise and landing) shall be demonstrated to be within component and system specifications. This shall include redundancy verification.	Verify that predictions of back pressure of vent systems, pressurization rates, collapse factors, and residual gas masses are within predicted and allowable performance tolerances.
(3) Main Propellant Tank Fill, Drain Dump and Engine Propellants Feed - Propellant system fill rates, level control, anti-vortex effectiveness, LH_2 tank insulation characteristics, and propellant NPSP requirements at the engines interfaces (including transient effects caused by engine shutdown simulating an inflight failure) shall be demonstrated.	Verify that fill rate capability is compatible with required rescue response time. Verify vortexing suppression is adequate at all propellant levels to minimize residuals, and verify that engine to vehicle CEI specifications and ICD requirements will be met during flight.
(4) Main Engines - The compatibility of the engine to vehicle mechanical electrical, avionics, fluid, gas and performance interface, including redundancy verification shall be demonstrated within the limits possible by ground testing. Engine throttling effects on the vehicle systems shall be demonstrated for minimum and maximum power levels.	The engine will be government furnished item which must be integrated into the vehicle without degradation to the engine.
(5) Acceptance tests of the main propulsion subsystems are required after installation of components, engines, tanks, and interconnecting tubing, piping and cabling.	Required to verify that the main propulsion subsystems have been properly installed and exhibit acceptable performance characteristics.

FIGURE 5.2–4

control devices; 4) Engine attached sections of heat shield.

Test Objectives:

- o Verify compatibility of stage hardware to engine system.
- o Access actuator control characteristics during the start transient.
- o Provide preliminary data on effectiveness of POGO suppression device to decouple the stage and engine system characteristics.
- o Provide engine manufacturer with data on structural loads imposed by stage hardware (actuators and heat shield).

Test Approach: The purpose of these tests are to provide a maximum of exchange of information between the stage and engine manufacturer. The above hardware would be delivered to support specific test requirements agreed upon between the engine and stage contractors and the NASA.

Rationale: These tests information are significant to both the engine and stage manufacturer and can be accomplished earlier by the engine manufacturer.

5.2.1.3.2 Propulsion Integration Test

Test Article: The applicable portion of the first production vehicle to be manufactured will be the test article. It will be a complete vehicle except that the wings, canard, airbreathing engines, guidance platform, and horizontal flight cockpit displays may be omitted. Main engines will be prototype assemblies. Suitable wiring terminations and pneumatic, hydraulic, propellant, and structural closures will be effected at the interfaces of all omitted items. Some TPS areas will be modified or substituted for the tests, as needed to provide protection of the basic structure from the increased exposure to ground-reflected acoustics.

Test Objectives

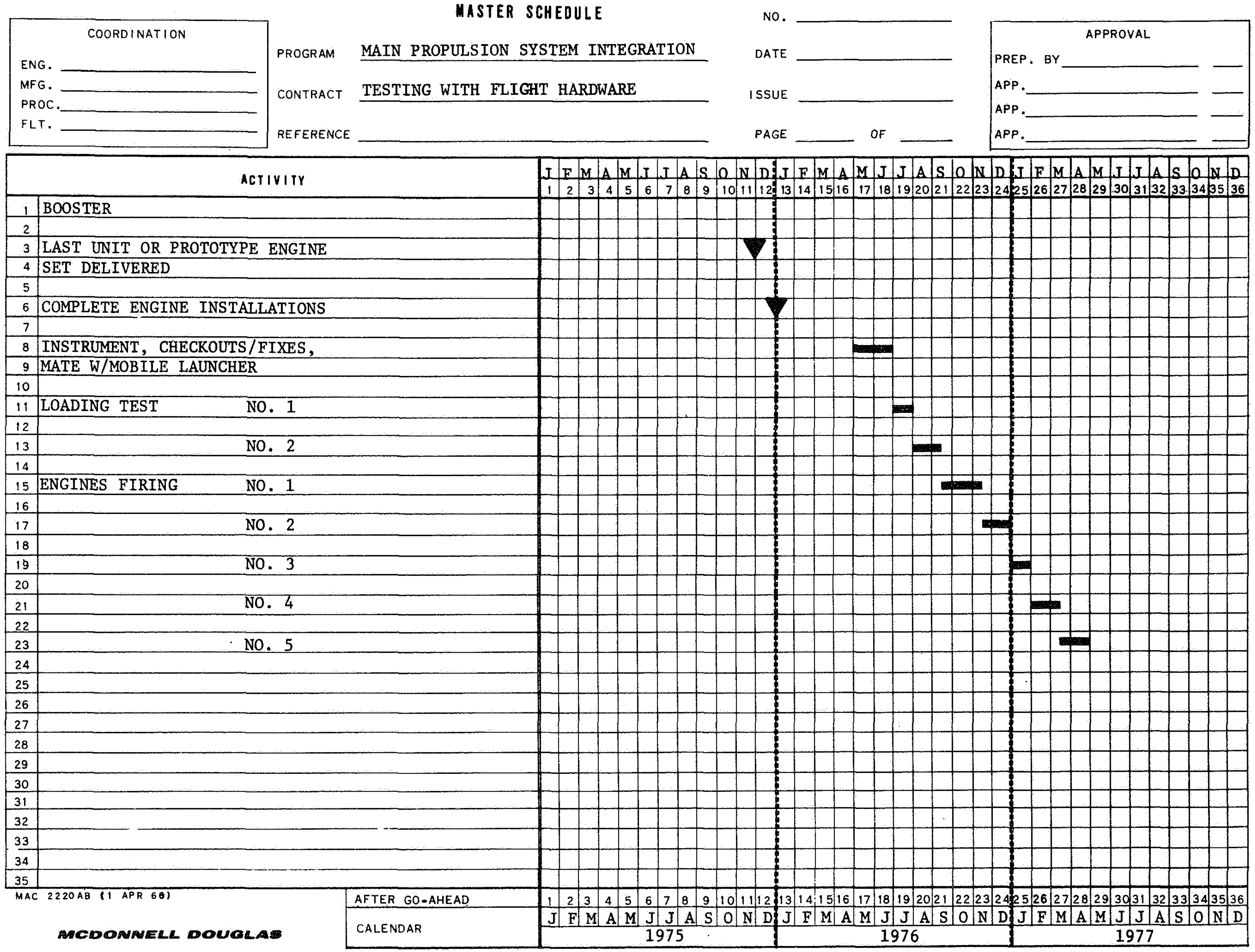
- o Establish the compatibility of the vehicle, facility, and GSE and their capability to provide controlled vehicle pneumatics and liquid and gaseous propellant loadings and unloadings including maximum loading rates required for a minimum launch countdown time.

- o Demonstrate propellant tank safing techniques.
- o Demonstrate simultaneous propellant loading capability including minimum propellant loading time.
- o Establish the adequacy of the purge for the propellant tank annulus to maintain an inerted atmosphere and keep component temperatures within specification operational limits.
- o Determine the accuracies of the propellant tank level sensors (including over-fill sensors) and the capability of the GSE to maintain proper liquid levels.
- o Determine the heat leak and boiloff characteristics of the LH_2 tank (surface agitation and ullage back pressure from the vent system).
- o Determine LO_2 and LH_2 prepressurization rates and define change in liquid level due to pressurization. Establish the effectiveness of the main tank pressurization diffuser and compare the ullage gas collapse factor to predicted values.
- o Verify satisfactory engine feed system chilldown and net positive suction pressure (NPSP) characteristics for engine prestart.
- o Demonstrate the capability of the APU to supply electrical and hydraulic power for the vehicle requirements.
- o Demonstrate the ability of the engine actuators to control engine position throughout the flight gimbal angle envelope.
- o Verify the compatibility of the ACPS engines with structure and avionics.
- o Demonstrate satisfactory LOX feed line circulation (NPSP and lack of geysering).
- o Verify that engine start and shutdown transient conditions are within allowables (i.e., NPSP, flow of the GO_2, GH_2 and helium, electrical power,

and avionics operational characteristics).

- o Verify the characteristics of the thrust structure loading profile.
- o Determine the pressure control characteristics of the main tanks during the start transient.
- o Verify the capability of the pneumatic control and purge systems.
- o Demonstrate the engine actuator positioning control during the start, low level thrust and shutdown transients.
- o Verify vehicle-structure-to-engine dynamic coupling response within the limitations imposed by vehicle holddown.
- o Verify engine and vehicle main propulsion system performance at rated and reduced thrust.
- o Verify satisfactory vehicle system response and fuel supply characteristics during a single engine shutdown.
- o Verify performance of the depletion sensors.
- o Verify engine and vehicle compatibility during maximum-rate gimballing response.
- o Verify engine and vehicle main propulsion system performance at emergency power level.

Test Approach: Testing is divided into cold flow tests and hot firing tests and are described below. A schedule of the proposed main propulsion integration tests is shown in Figure 5.2-5. The proposed test outline allows a progressive incremental system integration at a minimum risk and cost. Before each test the stage will complete the same checkout and pretest purges as required for a launch. Following each test the stage will be secured and maintenance performed utilizing the same facilities and equipment as for launch turn-around. A development instrumentation system will be installed to complement the operational instrumentation.


MASTER SCHEDULE
COORDINATION
ENG.
MFG.
PROC.
FLT.
PROGRAM MAIN PROPULSION SYSTEM INTEGRATION
CONTRACT TESTING WITH FLIGHT HARDWARE
REFERENCE
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DATE
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PAGE OF
APPROVAL
PREP. BY
APP.
APP.
APP.
ACTIVITY
1 BOOSTER
3 LAST UNIT OR PROTOTYPE ENGINE
4 SET DELIVERED
6 COMPLETE ENGINE INSTALLATIONS
8 INSTRUMENT, CHECKOUTS/FIXES,
9 MATE W/MOBILE LAUNCHER
11 LOADING TEST NO. 1
13 NO. 2
15 ENGINES FIRING NO. 1
17 NO. 2
19 NO. 3
21 NO. 4
23 NO. 5
AFTER GO-AHEAD
CALENDAR
1975
1976
1977
MAC 2220AB (1 APR 68)
MCDONNELL DOUGLAS

FIGURE 5.2–5

(1) Propellant Loading Test No. 1 - The initial propellant loading test will verify the proper functioning of the propellant systems and components in an operational mode including verification of avionics and compatibility with propulsion components. Propellant flow rates will be significantly reduced from design rates, and the LO_2 and LH_2 propellant tanks will not be loaded simultaneously. The pneumatic system will be charged and verified functional before the LOX loading begins. Once the LO_2 tank has been filled, including the ACPS LOX tank, a functional test will be performed on those components affected by the LO_2 and which can be operated safely. The LO_2 systems will then be unloaded and purged, including the ACPS LH_2 tank and a functional test performed on those components affected byLH_2 which can be operated safety. The LH_2 tanks will then be drained and purged.

The GO_2 and GH_2 accumulators in the ACPS will be charged, vented, and then purged, following the liquid propellant tests.

(2) Propellant Loading Test No. 2 - A set of small vibraters (shakers) will be attached to the stage before the second cold flow test. After erection onto the modified LUT the stage will be excited by these shakers to evaluate the stage damping characteristics and modal shapes.

The second propellant loading test will be conducted similar to the first test except that the propellant flow rates shall be at their maximum design conditions. Propellant sensing compatibility and avionics control capability at these maximum flow rates will be demonstrated. The LOX will not be unloaded before the LH_2 fill in order that the propellants may be unloaded simultaneously. During the simultaneous propellant unloading the shakers will be excited in order to establish stage damping as a function of propellant level.

After main propulsion cryogenics have been unloaded and the ACPS-APU common gaseous propellant accumulators are still pressurized, the O_2-H_2 APU system will be started. Ground supplied GO_2 and GH_2 supplies will be terminated allowing the ACPS propellant conditioners to operate and recharge the ACPS gas supplies. Electrical power will be transferred from the ground supply to the vehicle source and vehicle hydraulics will be used to position the main engines over their maximum gimbal angle range. The JP-fueled APU combustor turbine power source will be started and power transferred from the O_2-H_2 system to the JP-fueled system. The APU will be shut down and ground electrical power supply reestablished. Each ACPS engine installed will be fired for a minimum pulse duration. The ACPS cryogenic storage tanks will be drained and purged. The ACPS-APU common gaseous propellant tanks will then be vented and purged. The shakers utilized during this test will be removed before the first firing test.

(3) Engine Firing Test No. 1 - The propellant loading for this test will be at nominal flow rates. The two propellants will be loaded simultaneously, similar to a launch countdown. It is desirable that only a small fraction of the main propellants be loaded for the first firing, since this firing will be scheduled for only a 10-second duration at a reduced thrust level. However, it may be desirable to fill the propellant tanks, in consideration of the time required to prepressurize a large ullage volume and in order to meet the start transient NPSP requirements.

A component functional check will be completed following propellant loading. A stage final launch countdown sequence will be initiated including starting APU's and switching to internal power. Main engine start will be initiated utilizing the proposed engine start launch staggering sequence. Engine thrust will be limited to the 50% level to evaluate NPSP start transients and provide minimum thrust structure loading. The engine firing duration will be limited to approximately 10 seconds. The short duration test will allow a detailed evaluation to be made of the stage and GSE and facility systems capability before subjecting them to more severe conditions.

(4) Engine Firing Test No. 2 - The propellant loading and pretest functional will be the same as in firing test No. 1. Following the launch countdown sequencing, the main engines will be started and commanded to the 100% thrust level, similar to the launch condition. The engines will be allowed to operate for 30 seconds before being commanded to shutdown. This will allow the structure to be subjected to its maximum start shock loads and provide sufficient engine running time to allow propulsion system transient conditions to stabilize.

(5) Engine Firing Test No. 3 - The propellant loading and component functional checks will be the same as in firing test No. 1. This test will be a full duration firing within limitations possibly imposed by facility requirements or vehicle structural limitation. The countdown sequence will follow the proposed launch sequence including external to internal power transfer and termination of ground supplied stage helium, GO_2 and GH_2. The ACPS propellant conditioners will be operated similar to boost flight. Avionics monitoring and control will be the same as boost flight. After the main engines have started and accelerated normally to 100% thrust, the thrust level will be sustained until all predictable transients have stabilized. At this time, a slow-response gimballing check will be made which will position the main engines throughout the gimbal envelope. The engines will be center positioned and throttled to less than 100% thrust. After stabilization at a reduced thrust level, one engine will be shut down, simulating an inflight engine failure late in the booster powered flight. The thrust level on the remaining engines will be held constant in order to isolate any transient effects caused by the single engine shutdown. Shutdown of the remaining engines will be commanded from the depletion sensors. The residual propellant level after shutdown will be determined in order to evaluate the depletion sensors and the capability of the antivortex system to provide minimum residuals.

(6) Engine Firing Test No. 4 - Propellant loading, vehicle preparation, and

countdown sequencing will be the same as in previous test countdowns. Following engine start and stabilization at 100% thrust, an engine will be shutdown. The remaining engines will be held at constant thrust momentarily to allow any transients caused by the engine shutdown to be isolated and evaluated. The remaining engines will then be increased to their maximum emergency power thrust level, allowed to stabilize, and then reduced to 100% thrust. After stabilization at 100% thrust, a maximum-rate gimballing exercise will be performed. The remaining engines will be shutdown by the depletion sensors.

(7) Engine Firing Test No. 5 - Firing test No. 5 may be similar to No. 4. It is probable that the choice of engines to be shutdown will be predicated only on the LO_2 feed subsystem conditions, but it may be necessary to perform a similar test based on the predicted characteristics of the LH_2 system. In addition, certain conditions not covered by previous tests, due to hardware inability or time limitations, may necessitate reruns of small portions of previous tests. One special test to be included during this test is the acquisition of POGO sensitivity data. With all engines on a branched LOX feed duct firing, the feed duct will be pressure pulsed by draining some liquid overboard and periodically stopping the flow by rapidly closing an overboard bleed valve. This technique causes a "water hammer" pressure transient which will be experienced by the entire LOX feed duct. Further detailed description of Test No. 5 will be determined by future requirements definition, retest requirements, or the necessity for greater emphasis on areas previously tested.

Facilities and Equipment - The operational launch complex, as modified for the Space Shuttle will be used. The Booster will utilize an operational Launch Umbilical Tower with production GSE for the above tests. If the facility or stage creates any limitations which will preclude full duration firings the number of test firings may be increased to provide sufficient test time to satisfy all objective requirements.

Rationale - The major reasons for choosing this test article were: (1) It provides a configuration compatible with the referenced requirements; (2) It provides the least-cost approach to development testing with acceptable risks (in comparison to the cost required to build a separate, dedicated test article in conjunction with use of a static test stand at another location); (3) It allows the earliest date possible for main propulsion integration testing because of the GFE prototype main engine delivery schedule. Following testing, prototype engines will be returned to the government for possible refurbishment and use as flight spares. All other test article hardware is considered reusable for flight. Refurbishment of the test article will include installation of production main engines and completion of manufacturing assembly and checkout. The vehicle will then be ready for a horizontal flight shakedown and delivery to the vertical flight test program.

5.2.1.3.3 POGO Assessment - POGO is an adverse dynamic coupling effect which can occur during flight between the stage fluids, lines, structure and engines. It is impossible to combine all of the flight conditions which cause POGO into a ground test to verify that this phenomenon will not occur in flight. The technical understanding of the POGO phenomenon is sufficient that analytical expressions describing its effect have been derived. The unknowns, or variables, in these expressions can be defined by several different ground tests. The final verification can only be made through actual flight demonstration.

The MDC team approach to POGO assessment is to define component characteristics, model analytical unknowns impractical to test full scale, determine overall stage dynamic characteristics and then couple this information analytically with the engine influence conditions defined by engine development testing.

The primary component to be tested is the main LOX propellant feed duct. This will be done by defining the line lateral dynamic characteristics with stage attachment fittings representing the analytically predicted stage attachment characteristics. The axial dynamic characteristics will then be determined including the line axissymetric bulging.

The stage dynamic characteristics assessment is described in detail in Section 5.1.4. One test is specifically for POGO assessment. The LOX tank aft bulkhead fluid interaction definition will be determined by full scale testing of the LOX tank with partial tank fluid volumes to determine the axissymetric tank bulging characteristics. If the acceleration masses are excessive for state-of-the art shakers a scaled tank will be required to simulate these structural conditions.

The entire stage will be excited in the horizontal position (dry)(paragraph 7.2) and vertical position (dry and wet) as described in Paragraph 5.2.1.3.2 to access modal shapes and modal damping. Additional modal shape and damping will be available from the horizontal flight testing.

Main engine turbopump cavitation compliance and influence coefficients defining propulsion changes with changes in feed system conditions will be supplied by the engine manufacturer.

The above ground test data can be combined analytically to determine the stages susceptibility or resistance to the POGO phenomenon.

5.2.1.3.4 Flight Readiness Firing - The booster utilized for the first vertical launch will be required to undergo a Flight Readiness Firing (FRF) before its launch. The booster configuration for the FRF will be the same as that required for launch. The orbiter will be attached for this test. The purpose of the FRF is to provide a total system verification. As an integral part of this test the main propulsion systems propellant loading control, measurement, prepressurization, pressurization, conditioning, vent and relief systems, pneumatic system supply and regulation, external tank purges, engine performance and all operating, maintenance and checkout procedures will be demonstrated.

5.2.1.3.5 Horizontal Flight Testing - Specific main propulsion system testing is not feasible during the horizontal flight test phase. Flight rated main propulsion systems will be installed in boosters S/N 3 and S/N 2 and exposed to the airplane flight and landing environments during the horizontal checkout flying on these boosters, prior to utilization for vertical test flights.

5.2.1.3.6 Vertical Flight Testing - The final verification of the Booster main propulsion system will be made during the vertical flight test program. Emphasis will be placed on propellant tanking techniques, propellant feed duct characteristics, and preburn engine conditioning to verify operation within the design limits. Engine start and cutoff transient characteristics, as well as steady-state performance (thrust, I_{sp}, mass flow), will be verified to be within design limits and consistent with the requirements specified in the CEI and other applicable subsystem specifications. The absence of POGO will be verified. Operation of the pressurization system of the cryogenic propellant tanks within the design limits and according to the applicable performance requirements will be verified. The ability of the avionics system to throttle the booster rocket engines will also be verified. Data will be correlated with predicted data and ground test data where applicable. These tests will be the first to impose liftoff shock loads to the structure and main propulsion system.

During the booster flight program some variations in booster cryogenic and JP-4 propellant load will be employed to exercise the avionics system and to maintain entry conditions below the nominal heating and structural load levels.

Temperature and vibration effects on the main propulsion system during entry and cruiseback will be evaluated.

5.2.1.3.7 Acceptance Testing

Main propulsion system acceptance is accomplished by a post manufacturing checkout and a static firing demonstration (FRF). Following manufacturing each component will be functionally checked and a detailed verification made that each

LRU performs within operational tolerance limits. These tests will also verify all redundant functions of each subsystem. Acceptable leakage rates will be an integral part of each LRU checkout.

An integrated systems test will follow the detailed subsystem checkout. This test will verify that the main propulsion system responds normally while other subsystems are being functioned simultaneously similar to a launch condition.

The main propulsion system will be actively functioned during the FRF. The propellant system loading control, accuracies, insulation effectiveness, propellant conditioning and pressurization system will be functioned under operational launch conditions. The pneumatic system will be charged and functioned for component actuation and Booster purges including engine purges. The main engines will be fired long enough to allow stabilized propulsion performance. This will allow a verification of engine interface requirements (NPSP, GO_2 and GH_2 flow, purges, avionics signals and electrical power) and a check on structural and hydraulic interfaces. A successful post firing system securing including purging, maintenance and checkout will provide final main propulsion system acceptance. Revalidation of the main propulsion system acceptance after each launch will be accomplished utilizing post manufacturing checkout techniques and previous flight data for subsystems verification. Primary emphasis will be upon use of past flight data for system reacceptance.

5.2.2 <u>Attitude Control Propulsion System</u>

5.2.2.1 <u>Subsystem Description</u> - The Attitude Control Propulsion System (ACPS) must provide three-axis attitude control from Booster main engine shutdown thru coast to apogee and reentry until the aerodynamic control surfaces provide attitude control for cruiseback flight. The ACPS is a high-pressure GO_2/GH_2 bi-propellant reaction control system. Subcritical storage liquid hydrogen and oxygen are conditioned to high-pressure gas by a gas-generator-powered turbopump/heat exchanger cycle. The conditioned gas is stored in accumulators for distribution to the appropriate equipment. The ACPS propellant is stored in tanks which must also supply propellant for the auxiliary power units (APU). The propellant conditioning functions for the APU are performed by the ACPS conditioning equipment. A schematic of the Booster ACPS system is shown in Figure 5.2-6.

5.2.2.2 Test Requirements And Justification - The test requirements for the ACPS are presented in Figure 5.2-7.

ACPS Test Requirements

Test Requirement	Justification
(1) The capability of the liquid propellant storage and supply subsystem to be drained, purged, and filled and to supply liquids to the conditioning subsystem propellant pumps shall be demonstrated, including pertinent considerations of zero gravitational environment and force field build-up of the reentry flight phase. Sufficient propellant capacity to produce minimum total impulse requirements including APU consumption requirements shall be demonstrated.	It is necessary to develop these components separately because of their advanced technology requirements.
(2) The capability of the liquid propellant conditioning, gaseous storage and distribution subsystem to receive liquids from the supply subsystem, pump them to high pressure, convert them to gas, store them in accumulators, and supply the engines, ACPS conditioning equipment and other using sources on demand, within design tolerances, shall be demonstrated.	Total propellant consumption (boil-off, ACPS engine consumption, ACPS conditioning equipment consumption, APU consumption, etc.), ACPS engine performance, and total ACPS subsystem performance must conform to the Booster CEI specification and ACPS propellant conditioning and supply subsystem specifications.
(3) The ACPS engines shall be developed and qualified to the contractor specifications.	To assure engines operation and performance to vehicle design and operational requirements.
(4) Acceptance tests of the ACPS subsystems are required after installation of components, engines, tanks, and interconnecting tubing, piping, and cabling.	Required to verify that the ACPS subsystems have been properly installed and exhibit acceptable performance characteristics.

FIGURE 5.2-7

5.2.2.3 Test Approach and Rationale

5.2.2.3.1 ACPS Test Unit - This section describes the major dedicated ACPS integration ground test program. Other ACPS testing will also be accomplished in

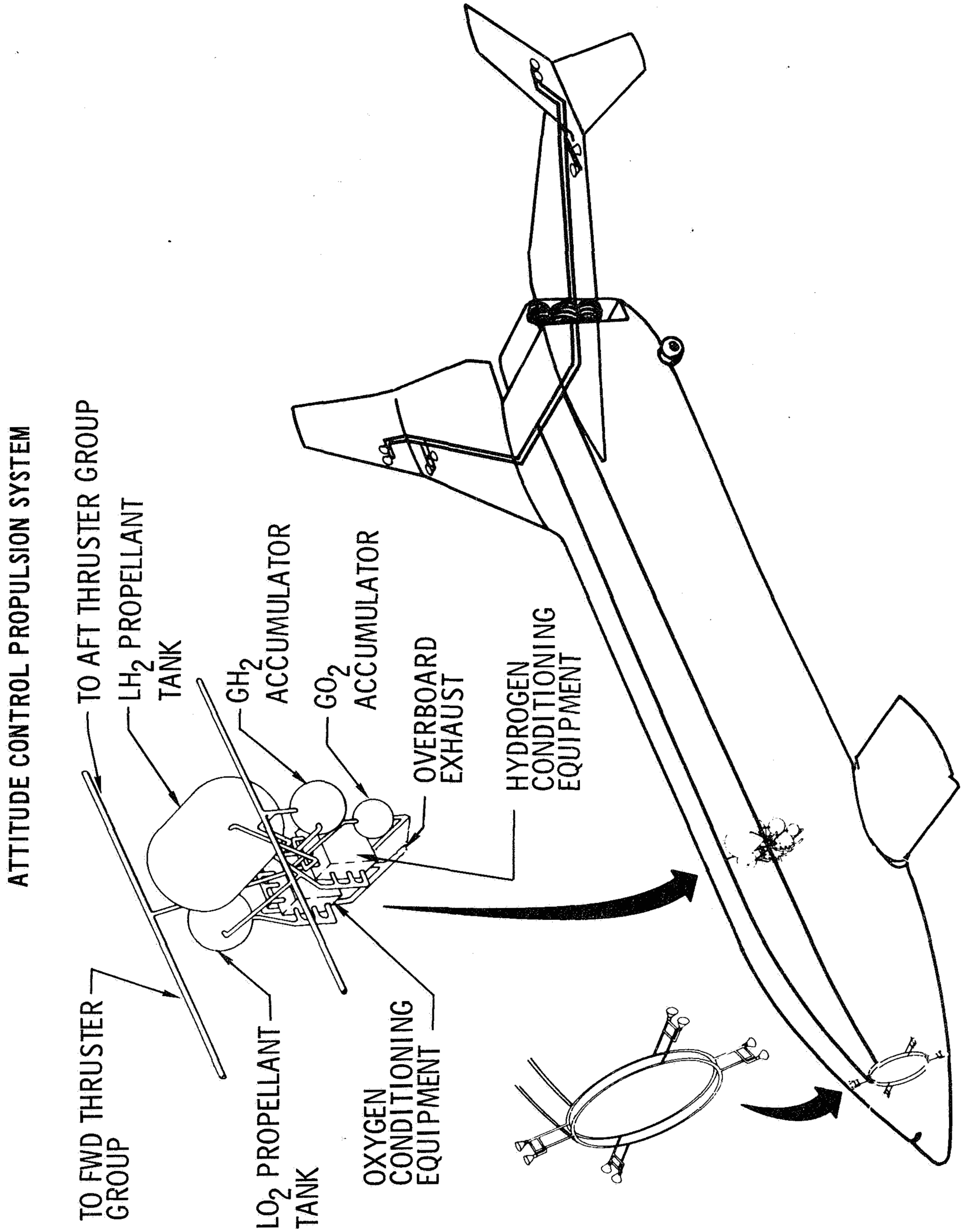
ATTITUDE CONTROL PROPULSION SYSTEM
TO AFT THRUSTER GROUP
LH_2 PROPELLANT TANK
GH_2 ACCUMULATOR
GO_2 ACCUMULATOR
OVERBOARD EXHAUST
HYDROGEN CONDITIONING EQUIPMENT
TO FWD THRUSTER GROUP
LO_2 PROPELLANT TANK
OXYGEN CONDITIONING EQUIPMENT

FIGURE 5.2–6

conjunction with main propulsion testing, as described in Section 5.2.1, and the flight readiness firing test, as described in Section 7.2. Section 5.1.7 tabulates the structural verification testing of the LO_2 and LH_2 tanks. Section 5.2.4 describes APU testing that will be done in conjunction with the ACPS development test program.

The ACPS cryogenic propellant storage tanks will be components developed individually by MDC. Testing will include development and verification of the propellant retention, tank pressurization and tank insulation using sub-scale and full-scale test articles with appropriate environmental simulation. The turbomachinery, controls, power head (combustor) heat exchanger and storage vessels will be developed as components by subcontractors. The ACPS engines will be developed and qualified under subcontract by an engine manufacturer. Testing will include operation and performance in simulated vacuum conditions. The ACPS engines utilized for integration testing will be limited to the regeneratively-cooled nozzle section without the film-cooled extension. This will provide complete system simulation without creating any requirements for engine nozzle altitude simulation for ground testing. The prototype hardware described above, with a complete gas storage and distribution system, including redundancy, will be arranged spatially to represent the vehicle installation. The test article will represent the entire vehicle ACPS including its Digital Interface Units. Much of the hardware is common to the Orbiter ACPS, and completely separate prototype hardware for Booster and Orbiter ACPS testing is not required. A schedule of the ACPS testing activities is presented in Figure 5.2-8.

A complete set of three turbopump/combustor assemblies is required to identify the chilldown and startup characteristics of the pump and feed system after intervals of standby and/or total lack of previous use. Redundancy management will be exercised and total system temperature transients evaluated. Power head exhaust

MASTER SCHEDULE

COORDINATION
ENG. ______
MFG. ______
PROC. ______
FLT. ______

PROGRAM: BOOSTER ATTITUDE CONTROL PROPULSION TESTS
CONTRACT ______
REFERENCE ______

NO. ______
DATE ______
ISSUE ______
PAGE ______ OF ______

APPROVAL
PREP. BY ______
APP. ______
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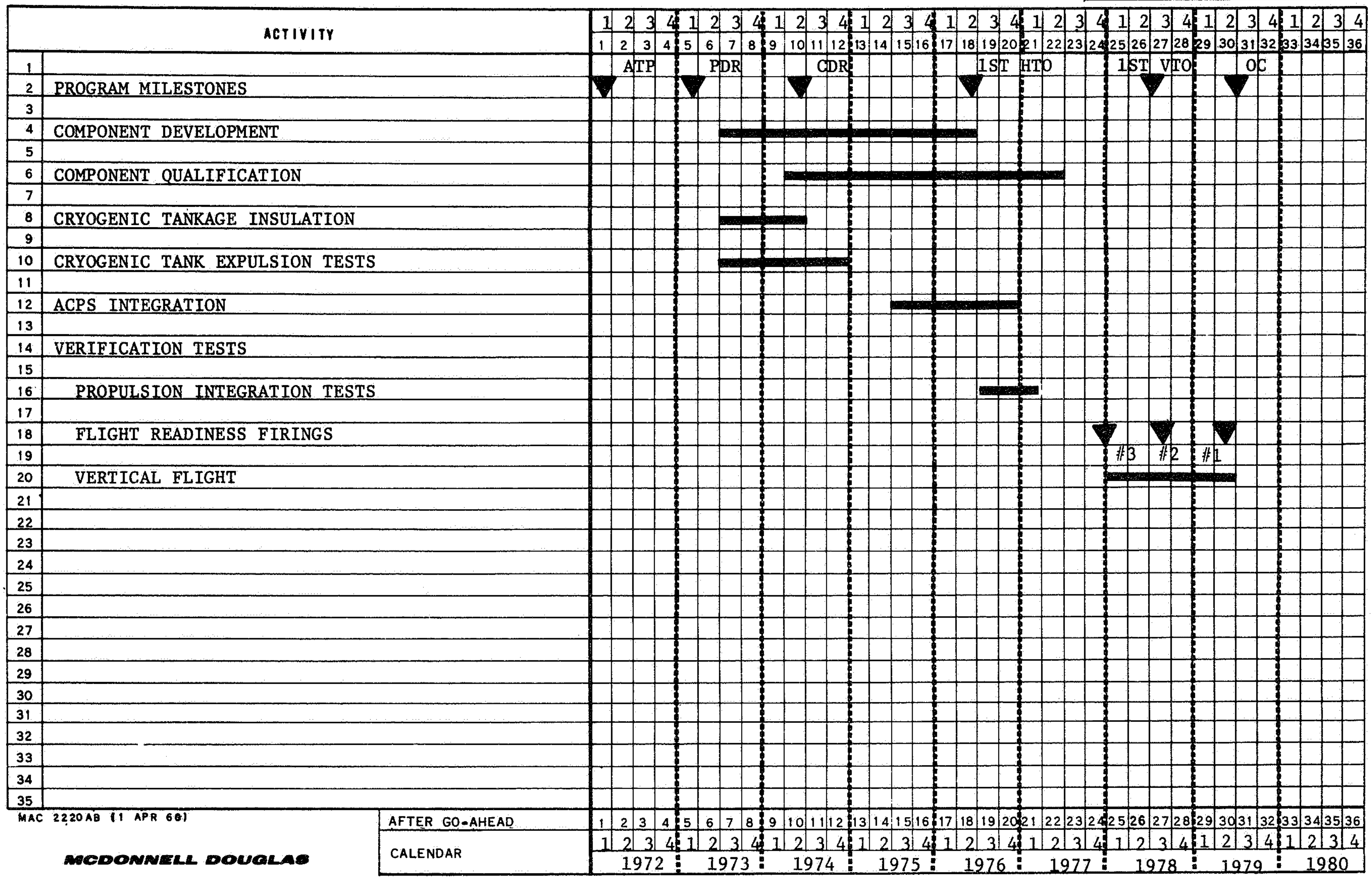


FIGURE 5.2–8

gases will be ducted through production ducting and stage disconnect to a facility disposal system.

Test Objectives

1. Develop fill, drain, venting, pressurizing, and purging procedures.
2. Verify cryogenic tank pressurization capability from GH_2 supply at limits of LH_2 flowrates.
3. Determine cryogenic pump initial and intermittent chilldown requirements.
4. Verify system response characteristics for minimim and maximum gas propellant consumption.
5. Verify fault detection and backup system response characteristics.
6. Verify combustor/turbine/heat exchanger performance characteristic at limits of propellant gas supply temperatures.
7. Verify propellant loading accuracies.
8. Verify system gas flow capacities under maximum flow condition.
9. Verify overall system efficiency and individual efficiencies (combustors, turbines, heat exchangers and engines).

Test Approach - The ACPS will be verified as a system before being tested in a vehicle. Testing will include making maximum possible demands on the propellant supply system, including the gas required for APU operation. Redundancy of operation will be demonstrated. Propellant loading, gas charging, unloading and purging procedures will be developed. Gas generator and APU performance characteristics will be evaluated during unbalanced temperature transitions in the stored gas supplies during transition from ground-supplied to vehicle-supplied gas (Reference Paragraph 5.2.4).

Facilities/Equipment - A test facility capable of supplying gaseous and liquid oxygen and hydrogen is required. Gases must be supplied at ambient and subcooled conditions. The instrumentation and control system will be stage hardware to the

Digital Interface Unit (DIU) with the remainder supplied by the ground facility. The facility must be capable of providing the following fluids:

Service	Pressure	Temperature	$\dot{W}$	Quantity
LOX	50 PSIG	-296°F	20 lb/sec	50,000 lb
LH_2	50	-420°F	5 lb/sec	15,000 lb
GOX	2500	AMB	16 lb/sec*	TBD
GOX	2500	-100°F	16 lb/sec*	TBD
GH_2	2500	AMB	4 lb/sec*	TBD
GH_2	2500	-200°F	4 lb/sec*	TBD
GH_e	4500	AMB	0.5 lb/sec	TBD
GH_e	4500	-400°F	0.5 lb/sec*	TBD
GN_2	2500	AMB	TBD	TBD

*These are short duration transients and may be provided by an accumulator blowdown. Flowrates shown occur at approximately 650 PSIG.

Instrumentation requirements are for 250 channels of pressure, temperature and flowrate type data (200 channels at approximately 10 samples per second (SPS) and 50 channels at approximately 100 SPS) plus 250 channels of sequence (discrete on-off) signals. The MDC team has adequate test facilities for these tests (e.g., Sacramento Test Center).

Rationale - The ACPS is a relatively small but complex subsystem, and would tie up an extensive facility and expensive flight-type hardware if the initial integrated development cycle testing were conducted during the main propulsion ground test firing described in Paragraph 5.2.1.3.2. With detailed ground tests, ACPS testing in a total vehicle installation (Reference Paragraph 7.2) can be limited to final verification of subsystems ard intra-subsystem operation.

5.2.2.3.2 Propulsion Integration Tests - The propulsion integration test article will have a complete ACPS except for wing-mounted thrusters. The system will be utilized to verify compatibility with all interrelating subsystems and will functionally supply O_2 and H_2 gases to the APU's during the propulsion integration tests. Operational ACPS system purging, filling, pressurizing, propellant management, maintenance and checkout techniques will be developed and verified during this test period.

5.2.2.4.2 Flight Readiness Firing (FRF) - Each Booster will be subjected to an FRF before being utilized as a vertical launch vehicle. This test is the primary integration verification of the ACPS system with all other stage subsystems. The stage will be fully flight configured and hardware sequencing and performance requirements will be similar to that expected for launch. The propellant filling, measurement, control, pressurization, expulsion and consumption requirements will be verified. The propellant conditioning equipment will be exercised to verify its performance and redundancy characteristics. This test will also provide the final verification demonstration of operational, maintenance and checkout procedures and techniques. Each ACPS engine will be fired for a minimum impulse bit to verify its proper performance.

5.2.2.3.4 Vertical Flight - The performance of the ACPS system will be verified during the flight. The flight is the only test condition which combines propellant conditioner operation and zero "G" condition simultaneously. Long duration and minimum impulse durations will be evaluated on the ACPS engines.

5.2.2.5 Booster ACPS Acceptance Testing _ Booster ACPS acceptance testing will begin with post manufacturing checkout and will be completed with the successful checkout following the Flight Readiness Firing (FRF). Each ACPS component will be functioned and checked out to verify it meets its operational specification requirements which can be verified during the post manufacturing subsystem checkout.

These tests will verify all redundancy as well as perform component leakage and functional tests. The ACPS will then be functioned as a part of the booster integrated subsystems checkout to verify its compatibility simultaneously with other subsystems similar to a launch condition. The booster will then be subjected to an FRF where the liquid propellant fill, drain, vent, pressurization, expulsion and management subsystems will be verified with cryogenics. Each propellant conditioning unit will be cycled to verify its functional performance. Each ACPS engine will be fired for a minimim stabilized firing duration to verify its operation. The ACPS will be drained, purged and checked out following the FRF to verify the system has not experienced unexpected degradation. The ACPS will have completed all acceptance requirements by the post FRF checkout.

5.2.3 Airbreathing Engine System

5.2.3.1 Airbreathing Propulsion System Description - The airbreathing propulsion system consists of 10 low-bypass turbofan engines which will operate after return into the atmosphere and provide sufficient thrust to return the Booster to the launch site. The engines provide sufficient thrust to allow the Booster to cruise at or above 10,000 feet altitude with nine of the ten engines operating. The propulsion system must withstand the natural and induced environments encountered during shipment, storage, and operational use including suspension in the vertical position, during on-pad checkout and Booster ascent flight.

The airbreathing propulsion system consists of the airbreathing engine, engine installation, engine inlet, inlet anti-icing, fire protection, fire detection, fire extinguishing, starting, instruments, and engine exhaust which must function in an overall interrelated manner to provide power for flight within the atmosphere. A schematic of the Booster Airbreathing Engine System is presented as Figure 5.2-9.

5.2.3.2 Test Requirements And Justification - The Booster airbreathing engines system test requirements and justification are presented in Figure 5.2-10.

SINGLE BODY CANARD BOOSTER CRUISE PROPULSION SYSTEM

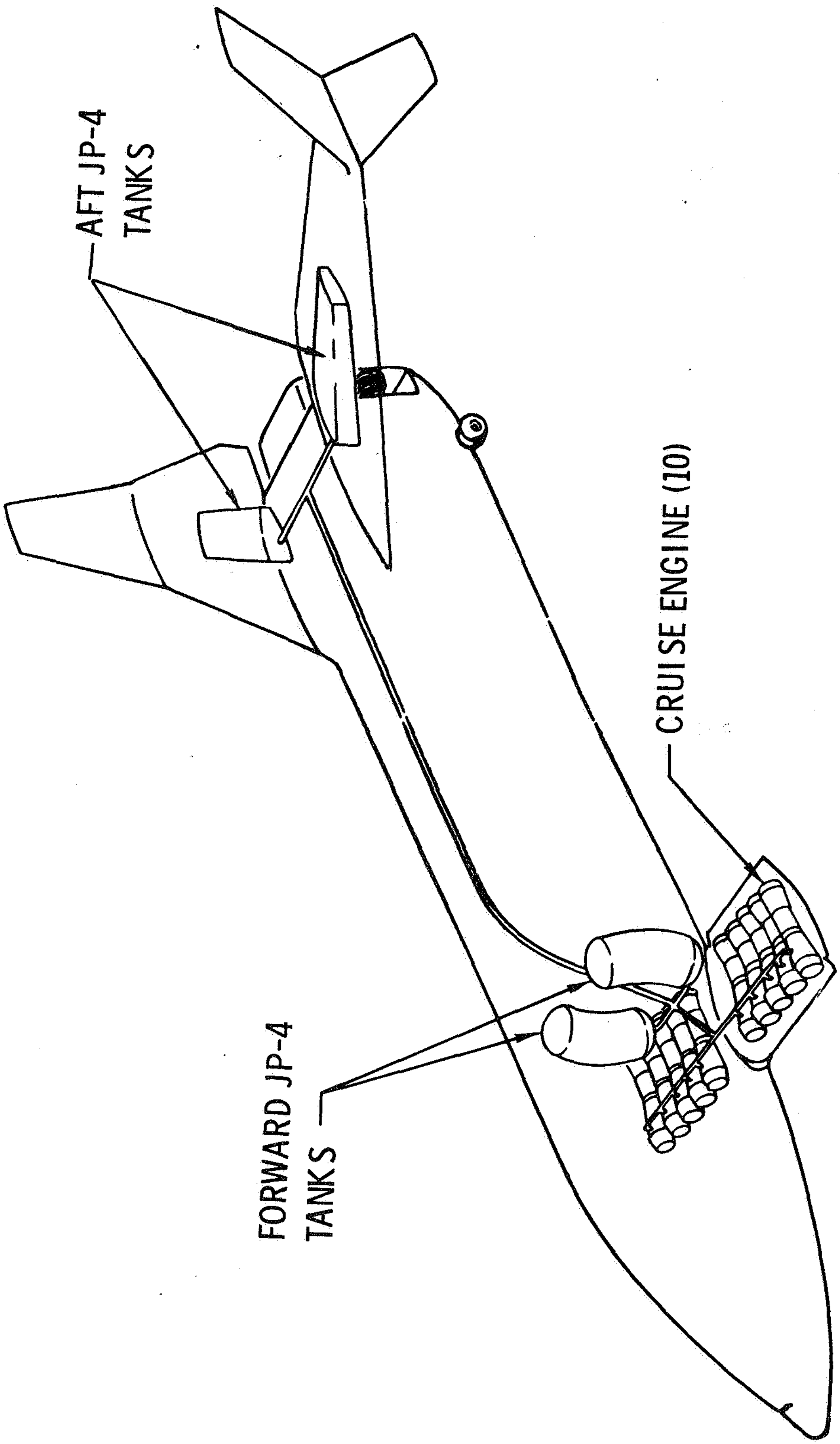


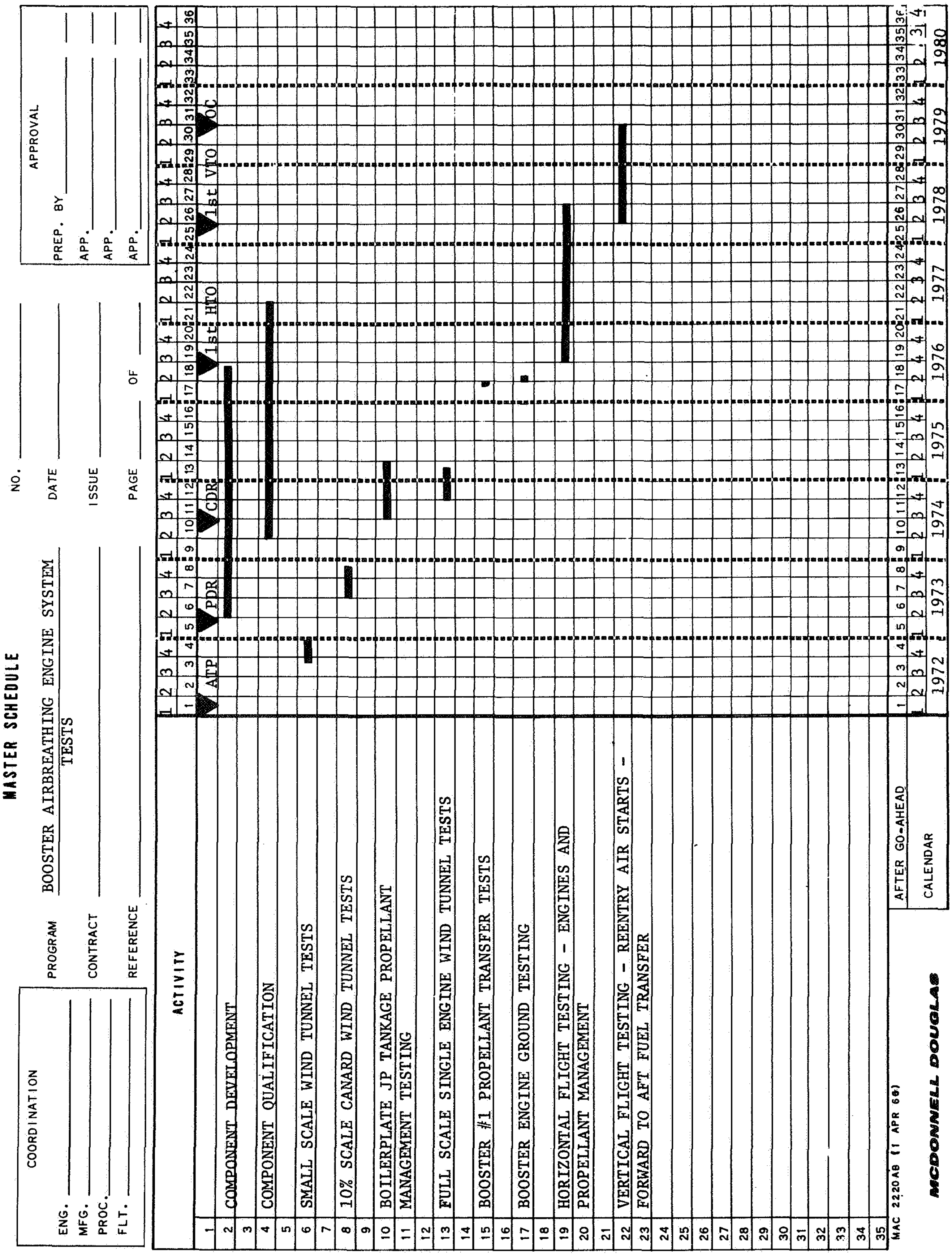
FIGURE 5.2–9

AIRBREATHING PROPULSION SYSTEM TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
(1) Fuel fill, drain, feed and transfer subsystem.	
(1.1) The design capability to fuel the subsystem in both the vertical and horizontal vehicle position shall be demonstrated.	The satisfaction of the complex design requirements necessary to allow the vehicle to be fueled on the launch pad for launch mission flexibility as well as horizontally for ferry flights should be assured prior to flight test.
(1.2) The design capability to transfer fuel between tanks as required for center of gravity control shall be demonstrated.	To assure capability to make total fuel load available for engine consumption without deleterious effect on vehicle controllability.
(1.3) The design capability to supply fuel to the engines at the appropriate pressures and flow rates shall be demonstrated.	This is a prerequisite to attempting flight operations for vehicle safety and mission goal assurance.
(1.4) The design capability of the fuel tanks to be pressurized during flight to maintain internal pressure above external ambient pressure shall be demonstrated.	JP fuel tanks are not capable of withstanding potential negative pressuring during reentry or as a result of cruise consumption; therefore, this is a safety-of-flight requirement.
(2) The design capability of the airbreathing engines to perform in their installation with respect to the air ingestion and exhaust systems and the jetblown flap shall be evaluated.	Ability to perform booster flyback is fully dependent on the safe operation and performance of the ABE and the associated inlet ducts and aerodynamic control surfaces. This testing is necessary to provide evolutionary development of a major segment of the configuration.
(3) Acceptance tests of the ABES subsystems are required after installation of components, engines, tanks, and interconnecting tubing, piping, and cabling.	Required to verify that the ABES subsystems have been properly installed and exhibit acceptance performance characteristics.

FIGURE 5.2-10

5.2.3.3 Test Approach and Rationale – A schedule of Booster Airbreathing Engine System Tests is presented in Figure 5.2-11.


MASTER SCHEDULE
COORDINATION
ENG.
MFG.
PROC.
FLT.
PROGRAM BOOSTER AIRBREATHING ENGINE SYSTEM TESTS
CONTRACT
REFERENCE
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ISSUE
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APPROVAL
PREP. BY
APP.
APP.
APP.
ACTIVITY
ATP
PDR
CDR
1st HTO
1st VTO
OC
COMPONENT DEVELOPMENT
COMPONENT QUALIFICATION
SMALL SCALE WIND TUNNEL TESTS
10% SCALE CANARD WIND TUNNEL TESTS
BOILERPLATE JP TANKAGE PROPELLANT MANAGEMENT TESTING
FULL SCALE SINGLE ENGINE WIND TUNNEL TESTS
BOOSTER #1 PROPELLANT TRANSFER TESTS
BOOSTER ENGINE GROUND TESTING
HORIZONTAL FLIGHT TESTING - ENGINES AND PROPELLANT MANAGEMENT
VERTICAL FLIGHT TESTING - REENTRY AIR STARTS - FORWARD TO AFT FUEL TRANSFER
AFTER GO-AHEAD
CALENDAR
1972
1973
1974
1975
1976
1977
1978
1979
1980
MAC 2220AB (1 APR 69)
MCDONNELL DOUGLAS

FIGURE 5.2–11

5.2.3.3.1 Fuel Subsystem Tests

Test Article - Prototype fuel subsystem components (e.g., pumps, valves, ducts, and test-agency fabricated tanks that represent the geometry, but not total capacity of the flight tanks) will be arranged in a spatial orientation representing the vehicle arrangement. This will include the fuel loading, transfer, and engine feed subsystems. The test rig will be capable of both horizontal and vertical operation, corresponding to the conditions required for horizontal take-off and ferry, and for VTO launch.

Test Objectives

- o Verify loading accuracies in horizontal and vertical orientation.
- o Verify propellant transfer between forward and aft tanks.
- o Verify propellant management system redundancies and failure detection capability.
- o Verify adequacy of the airbreathing fuel tank pressurizing system.
- o Verify propellant management system redundancies and failure detection capability.
- o Verify adequacy of the airbreathing fuel tank pressurizing system.

Test Approach: Fueling tests will be performed in the horizontal and vertical positions. Simulated flight fuel transfer and fuel feed tests will be performed with pressures, flows, and fuel quantity versus time being monitored in each tank. During these simulated flight tests, tank pressurization control will be evaluated.

Facilities/Equipment: A test facility suitable for accommodating the test article and storing, supplying, and receiving the hydrocarbon fuel will be required. The following instrumentation requirements must be met: 20 pressure measurements, 4 temperature measurements, 50 position indicator measurements, 60 command signals, 4 propellant levels, 4 flowrates and 14 current measurements. All measurements are at 10 samples per second except the current measurements, which will be at 100 SPS.

The MDC team has suitable facilities for these purposes (e.g., MCAIR or DAC Aircraft Fuel Systems Laboratories).

Rationale: This type of test program, which is like that normally employed on commercial and military aircraft programs, will assure the functional and performance capabilities needed to assure horizontal and vertical takeoff flight testing without tying up a vehicle for prolonged preflight time periods.

5.2.3.3.2 Airbreathing Engines System Tests

5.2.3.3.2.1 Scale Model Testing - Scale models will be utilized exclusively to define the inlet and exit nozzle configurations. A description of these tests and potential facilities and test hours are presented in Paragraph 4.1. Small scale models (i.e. 3%) will be utilized to evaluate basic geometry. A larger model (i.e. 10%) will be used to define the final loft lines for production. Testing will utilize inlet air bleeding to simulate engine intake air flow and both cold and hot gas at predicted engine pressure ratios for exhaust duct geometry definition. These tests will be an integral part of tests to evaluate the inlet door and jet flap characteristics. All of the model testing will be done with a minimum of a five (5) engine side of the canard. The following objectives apply to the model tests.

(1) Inlet Development Tests

- o Develop inlet geometry to obtain adequate inlet pressure recovery and maintain flow distortion within engine manufacturer's requirements.
- o Determine inlet performance over the Mach number, angle of attack, and altitude range of expected operations.
- o Determine inlet opening loads, dynamics, and start-up for the range of speed, angle of attack, and altitude at which inlets may be opened.
- o Determine effects of engine-out or inlet performance and flow distortion of adjacent engines.

(2) Exit Nozzle and Jet-Flap Development Tests (using cold and hot gas flow)

- o Develop exit nozzle geometry to obtain adequate thrust recovery and uniformity of flow over the jet flap.
- o Develop jet flap contour to obtain required jet deflection without flow separation and with good efficiency.
- o Determine the jet flap performance including direct and induced lift, pitching moments, downwash, and induced drag for the operational ranges of engine thrust, Mach number, altitude, angle of attack and flap deflection.
- o Determine effects of engine-out on jet flap performance, adjacent-engine thrust, and flow separation over the jet flap.
- o Determine jet flap actuation requirements, including hinge moments, deflection range and rates, and airloads in both the stowed and operating positions.

Rationale - The characteristics of the canard-jet flap and engine inlet conditions must be determined as a function of canard span. Large scale models will provide an adequate understanding of engine inlet, exit and the canard-jet flap characteristics that it can be safely committed to production hardware. The production vehicle can perform adequate ground tests prior to its first horizontal flight test to provide data for correlation of engine inlet and canard-jet flap performance with the wind tunnel predictions. Ground testing before the first horizontal flight will include full thrust runups, engine acceleration, calibration from idle to full power, and stage horizontal roll acceleration tests including raising the nose wheel from the ground. These tests will provide sufficient confidence to initiate the horizontal flight test program.

5.2.3.3.2.2 Full Scale Wind Tunnel Testing - A single engine segment of the

Booster canard will be tested in the AEDC 16T wind tunnel to evaluate different characteristics of windmill, cartridge and crossbleed engine starting during simulated reentry altitude changes. The inlet lip closure will be articulating similar to the production assembly. These tests are executed to require 350 tunnel occupancy hours including testing of the effectiveness of the fire suppression system at altitude conditions.

5.2.3.3.3 Horizontal Flight Testing - Preparations for horizontal flight testing begin as soon as manufacturing is completed. Propulsion ramp tests will include engine starting tests using cartridges and air crossbleed, engine power acceleration calibration tests, fuel metering calibration, Booster ground roll acceleration tests, jet flap performance tests including high speed taxi tests. Engine nacelle longitudinal thermal gradients will be mapped and the fire extinguisher system will be verified operational.

Engine power acceleration will be mapped for various initial power levels over the operating speed range of the Booster during the horizontal flights. The flight evaluation and verification will include engine handling and control, with data being obtained from steady state (at several power settings) and transient operation (slow, medium, and snap accelerations, and decelerations using various settings between idle and maximum power). This data will be recorded at several altitudes. The transient operation will be checked for at least two velocities at the test altitude and for single and multiple engine operation.

A pressure and temperature distribution survey will be made across the inlet to verify duct recovery and distortion characteristics throughout the inlet mass flow ratio range. Data will be recorded at two altitudes from minimum to maximum velocity. Angle-of-attack effects will be determined. Stall-free engine operation throughout the specified flight envelope will be verified concurrently with other flight test objectives.

The engine airstart characteristics will be evaluated and the available envelope defined. This will be initially verified for single engine airstarts. The testing will then be expanded to verify multiple engine airstart capabilities, and the preparation and starting of space modified engines.

Fuel consumption as a function of altitude, speed and gross weight will be determined. The capability and performance characteristics of the propellant transfer (foreward and aft as well as propellant feed to the engines) will be verified including fuel quantity measurement accuracies.

The antiicing performance of the airbreathing propulsion system will be verified. A government furnished tanker airplane will be required to provide a water spray for this operation.

5.2.3.3.4 Airbreathing Engines System Acceptance Tests - Airbreathing system acceptance tests will begin during post manufacturing checkout and will not be complete until after the Orbiters horizontal flight demonstration. Complete fuel and engine subsystem functionals will be made during manufacturing to verify functional and leakage requirements are met. Fuel loading accuracies and control capability will be demonstrated during ramp operations testing. CEI specifications, including engine power acceleration time, fuel flow requirements and Booster rolling acceleration requirements, will be demonstrated before the first horizontal flight. A limited demonstration of fuel flow vs altitude vs velocity will be verified during the horizontal flight tests. Engine power acceleration will be verified at maneuvering velocity. The airbreathing system will be accepted after meeting the post manufacturing and flight acceptance criteria defined in the CEI specifications.

5.2.3.3.5 Vertical Flight Testing - The primary objective in the vertical tests will be verification of the procedures and the capability of the system to function nominally after exposure to launch, ascent, entry, and transition conditions.

Proper operation of the jet flaps will be verified. Air start of the jet engines will be initially accomplished at a flight condition demonstrated during horizontal testing. The air start envelope will be expanded on subsequent missions, if feasible. The fuel system operation will be verified during the vertical flight test program. Fuel quantity system operation will be monitored during flight, and key fuel system pressures and temperatures will be measured.

5.2.4 Booster Auxiliary Power Unit

5.2.4.1 Subsystem Description - The Auxiliary Power Unit, consisting of four separate, independently controlled dual mode APU subsystems, must provide all hydraulic and AC electrical power requirements during the Booster flight. Each of the four APU subsystems consists of an O_2-H_2 combustor-turbine, a JP fuel combustor-turbine, and gearbox assemblies; the necessary lines, isolation valves, control valves and integrated control system; hydraulic pumps and AC generator; and those ancillary components required for lubrication and cooling.

The exhaust lines from the O_2-H_2 power turbines are manifolded together and vented overboard by means of a non-propulsive vent. The hydrogen and oxygen gases for APU operation are supplied from the regulated pressure gas supply manifold which distributes propellant gases to the ACPS engines. The hydrogen gas is passed through a series of heat exchangers to provide integral system cooling plus increase overall system energy efficiency. The oxygen gas is similarly heated prior to combustion. APU power is modulated consistent with system power demand. The capability for operation of the APU subsystems on the ground in maintenance areas is provided for by means of a separate gas connection to the turbine second stage wheel. Warm ground air will be supplied to obtain a power output of up to 50 HP.

The JP fueled power turbine obtains fuel from the airbreathing engine supply. This power supply is utilized during cruiseback flight to supply all hydraulic and electrical power requirements. A schematic of the auxiliary power system is presented in Figure 5.2-12.

5.2.4.2 Test Requirements and Justification - The booster APU test requirements and justification are presented in Figure 5.2-13.

BOOSTER AUXILIARY POWER UNIT TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
(1) The design capability of the auxiliary power unit to supply electrical and hydraulic power at all times shall be demonstrated.	To demonstrate compliance with the vehicle CEI specification and the APU subsystem specification.
(2) The compatibility of the APU subsystem with the ACPS supplied propellants, the hydraulic system components, and the electrical power and avionics shall be demonstrated.	Demonstrate subsystem interface compatibility.
(3) Acceptance tests are required after installation of the APU and the interfacing tubing and cabling.	Required to verify that the APU and interfacing subsystems have been properly installed and exhibit acceptable performance characteristics.

FIGURE 5.2-13

5.2.4.3.1 APU System Test Unit

Test Article: An entire APU, comprised of an O_2-H_2 combustor-turbine, a JP-fueled combustor-turbine, gear box, two hydraulic pumps, an electrical alternator, controller, instrumentation, DIU, and ancillary equipment will be tested as a unit. GO_2 and GH_2 supplies will be from the ACPS Test Unit described in Paragraph 5.2.2.3.1.

Test Objectives:

- Verify fault isolation and corrective action capability.
- Verify APU compatibility with ACPS gas supply.
- Verify satisfactory performance during propellant supply transition from ground supply to onboard ACPS cryogenic regenerative supply.

SHUTTLE BOOSTER
HYDRAULIC POWER SYSTEM

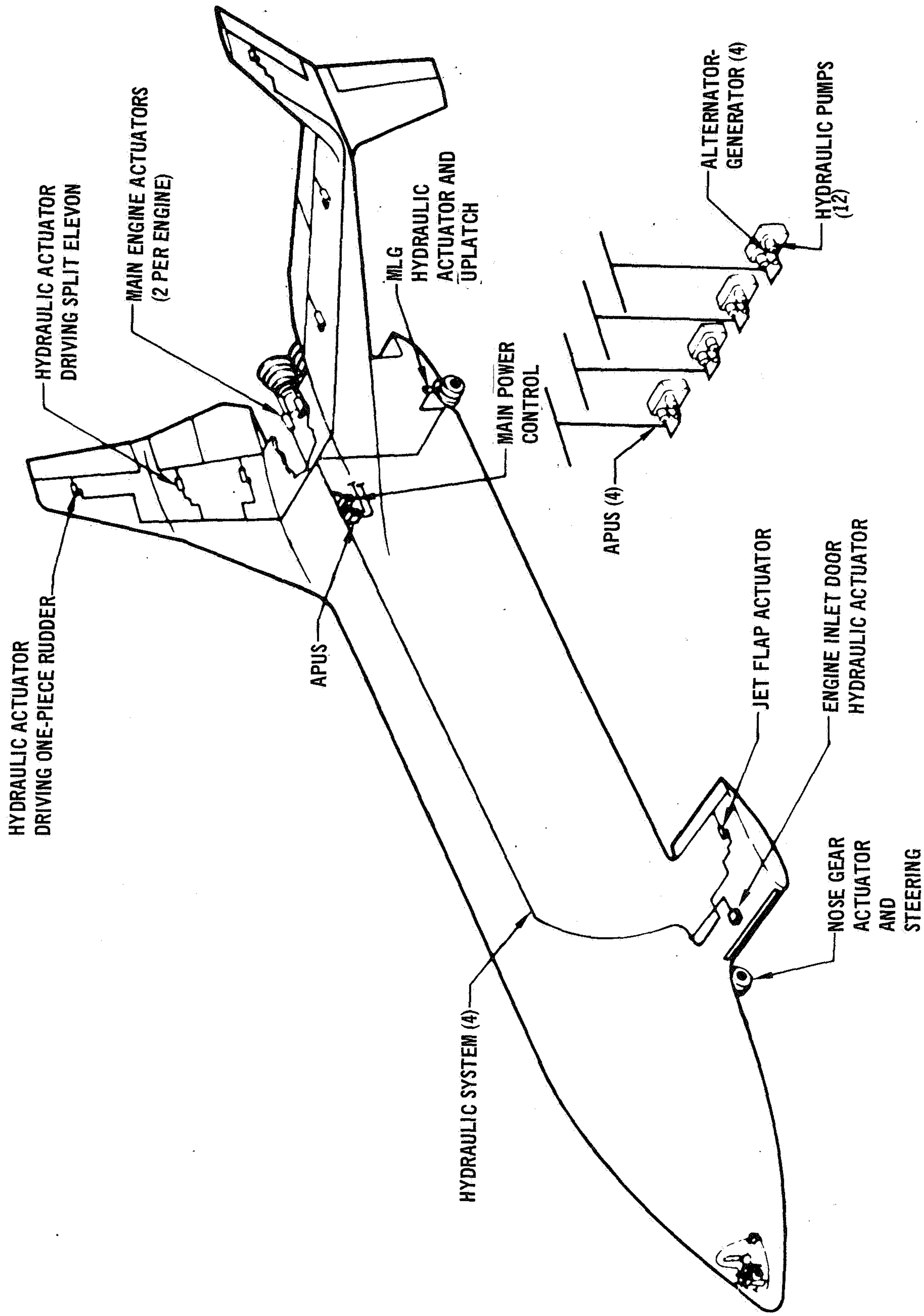
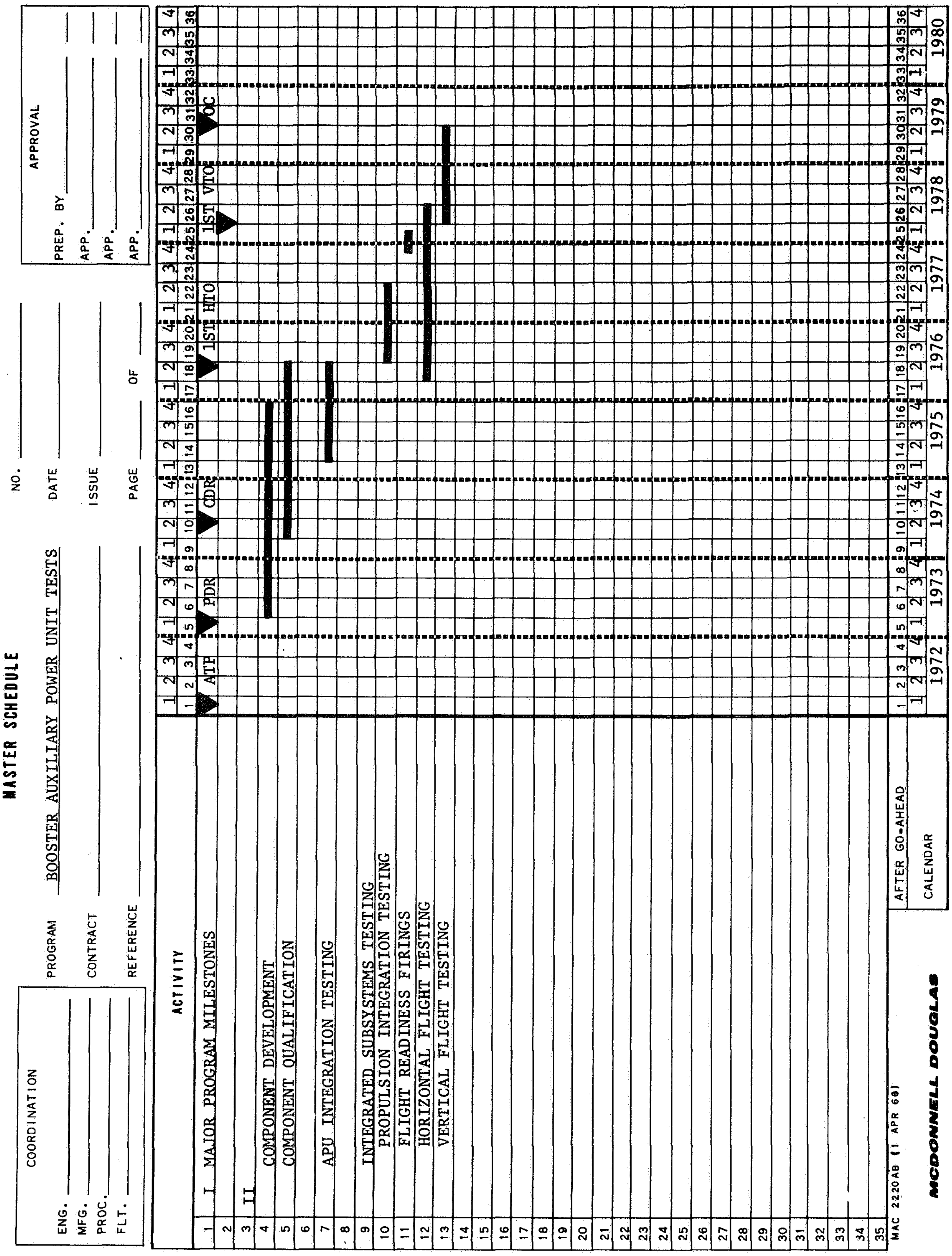


FIGURE 5.2–12

- Verify fluid system thermal balance (i.e., APU propellant gases temperatures equalized; gearbox cooled during simulated ground and flight operations; hydraulic pump drain cooling adequacy).
- Verify system response to flight simulated hydraulic and electrical loads and specification minimum and maximums.
- Verify power drive transfer from the O_2-H_2 fueled system to the JP-4 supplied system.
- Verify ground gas spin-up characteristics for checkout.
- Develop purge, checkout and LRU replacement procedures and techniques.

Test Approach: These tests will demonstrate the APU system control capability under varying hydraulic and electrical demands. These demands will be imposed through programmed facility systems simulating flight and design limit system loads. Single-component failure effects will be demonstrated by electrically or mechanically disabling a single component during a test. The satisfactory operation of the O_2-H_2 combustor will be demonstrated during the maximum predicted storage sphere gas temperature transients experienced during transfer from ground supply gases to the onboard converted cryogenic supplies. A schedule of the APU integration tests is shown in Figure 5.2-14.

Facilities: The facility must provide H_2 and O_2 liquids and gases, helium, and nitrogen services as described in Paragraph 5.2.2.3.1 plus JP fuel. Instrumentation recording must be provided for 120 parameters in addition to the ACPS measurements referenced above. Eighty of these measurements must be recorded at 10 samples per second (SPS) and 40 recorded at 100 SPS. These tests will be an integral part of the ACPS testing in order to obtain a higher degree of integration and utilize a minimum of expended ground test hardware.


MASTER SCHEDULE
PROGRAM BOOSTER AUXILIARY POWER UNIT TESTS
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ACTIVITY
I MAJOR PROGRAM MILESTONES
II
COMPONENT DEVELOPMENT
COMPONENT QUALIFICATION
APU INTEGRATION TESTING
INTEGRATED SUBSYSTEMS TESTING
PROPULSION INTEGRATION TESTING
FLIGHT READINESS FIRINGS
HORIZONTAL FLIGHT TESTING
VERTICAL FLIGHT TESTING
ATP
PDR
CDR
1ST HTO
1ST VTO
OC
AFTER GO-AHEAD
CALENDAR
1972
1973
1974
1975
1976
1977
1978
1979
1980
MAC 2220AB (1 APR 68)
MCDONNELL DOUGLAS

FIGURE 5.2–14

Rationale: Test results obtained from a complete APU unit are adequate to determine the entire system characteristics. In operational circumstances one unit must be capable of supplying all vehicle demands by itself and all units are normally operating continuously. Prototype or production hydraulic pumps and an alternator are required to verify interface compatibilities. Use of the actual ACPS propellant supply system reduces the quantity of expended flight hardware and reduces ground simulation requirements.

5.2.4.3.2 Horizontal Flight Testing - The JP fueled combustor-turbine will be used for most of the horizontal flight testing and performance demonstrations. Primary emphasis will be on demonstrating compatibility with the onboard avionics and structural subsystems as well as supplying hydraulic and electrical power. Air-starting of the APU combustors at altitude will be demonstrated similar to that which occurs following reentry.

5.2.4.3.3 Flight Readiness Firing (FRF) - The FRF will be the first firing of the O_2-H_2 powered combustor-turbine on the production booster. The primary purpose of this test is to verify the O_2-H_2 fueled APU powered capability during the transient loads imposed during the short main propulsion firing.

5.2.4.3.4 Vertical Flight Test - The APU will be subjected to normal variations in hydraulic and electrical demand and will experience up to 4.25 G's acceleration while operating. In addition the APU system will have been subjected to vacuum condition while operating. Smooth switching between the JP4 and cryogenic APU's will be verified. The performance characteristics from the tests described in Paragraph 5.2.4.3.2 will be compared to that predicted for these conditions based upon the ground development tests described in Paragraph 5.2.4.3.1.

5.2.4.5 Booster APU Acceptance Testing - Booster APU acceptance testing will begin with post manufacturing check out and be complete following a satisfactory subsystem check out following the FRF. A detailed component check out including leakage, functional and redundancy verification will be made as a part of the subsystem check-out following manufacturing. Performance must be within operational acceptable tolerances. The components will be exercised as a part of the combined subsystem check out to verify APU compatibility with related subsystems similar to a launch condition. The JP fueled APU combustor-turbine subsystem will be operationally functioned during ramp testing and horizontal flight test demonstrations. JP combustor performance, compatibility and redundance will be functionally demonstrated during these tests. The O_2-H_2 combustor-turbine performance will be functionally demonstrated during the FRF including a demonstration of the power transfer from the O_2-H_2 combustor-turbine to the JP fueled combustor-turbine subsystem. Performance for all tests must be within component and CEI specification limits.

5.3 Avionics Group

5.3.1 Integrated Avionics

5.3.1.1 System Description - The booster Avionics system implements the guidance and navigation, flight control, data management, communications and navaids, displays and controls, and software functions. Figure 5.3-1 is a simplified diagram which shows the avionics system features, the five subsystems, and the required equipment including those items unique to the orbiter or booster. Key feature of the system organization is that a centralized computer/data bus/ area multiplexing concept is used.

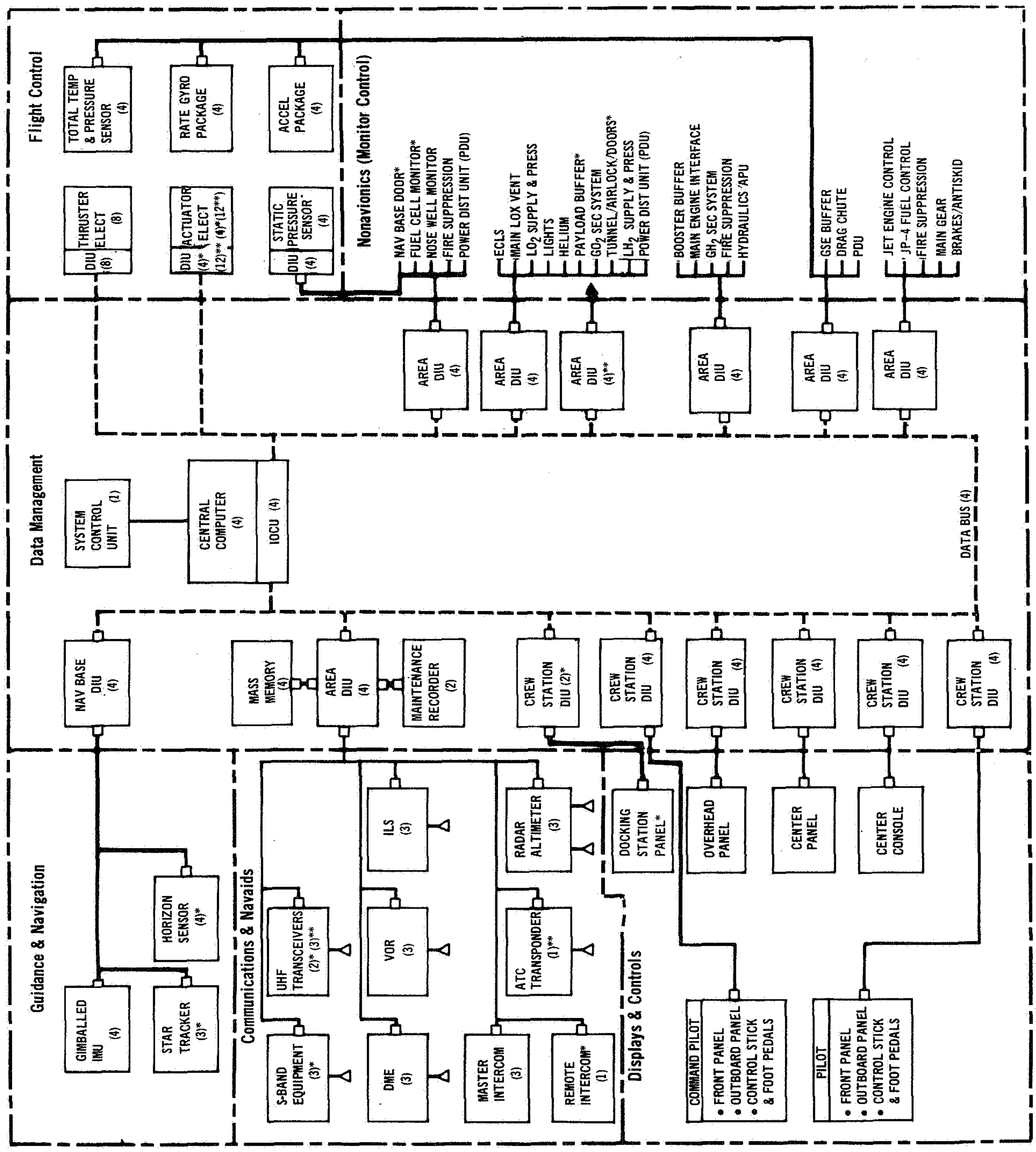
A fail operational-fail operational-fail safe capability is implemented by using four identical equipments for safety functions, three identical equipments for mission success functions, and either one or two identical equipments for convenience functions. Redundant strings of the avionics system are physically separated by installing the equipment into two major bays, one on each side of the vehicle near the cabin. Mid-ship and aft bays also accommodate avionics equipment. All equipment bays are accessible for ground maintenance. Figure 5.3-2 shows the equipment installation locations.

The system design is based on extensive use of techniques, concepts, and modified product line equipments that will have a significant development history by the 1972 time period either in space or aircraft programs.

Additional information about particular avionics subsystems is included in subparagraphs 5.3.2 through 5.3.7.

5.3.1.2 Test Requirements and Justification - The general avionics test requirements are delineated in Figure 5.3-3. Additional specific test requirements applicable to individual subsystems are noted in the applicable subparagraph

AVIONICS SYSTEM DIAGRAM



NOTE: *ORBITER ONLY, **BOOSTER ONLY.

FIGURE 5.3–1

BOOSTER AVIONICS INSTALLATION

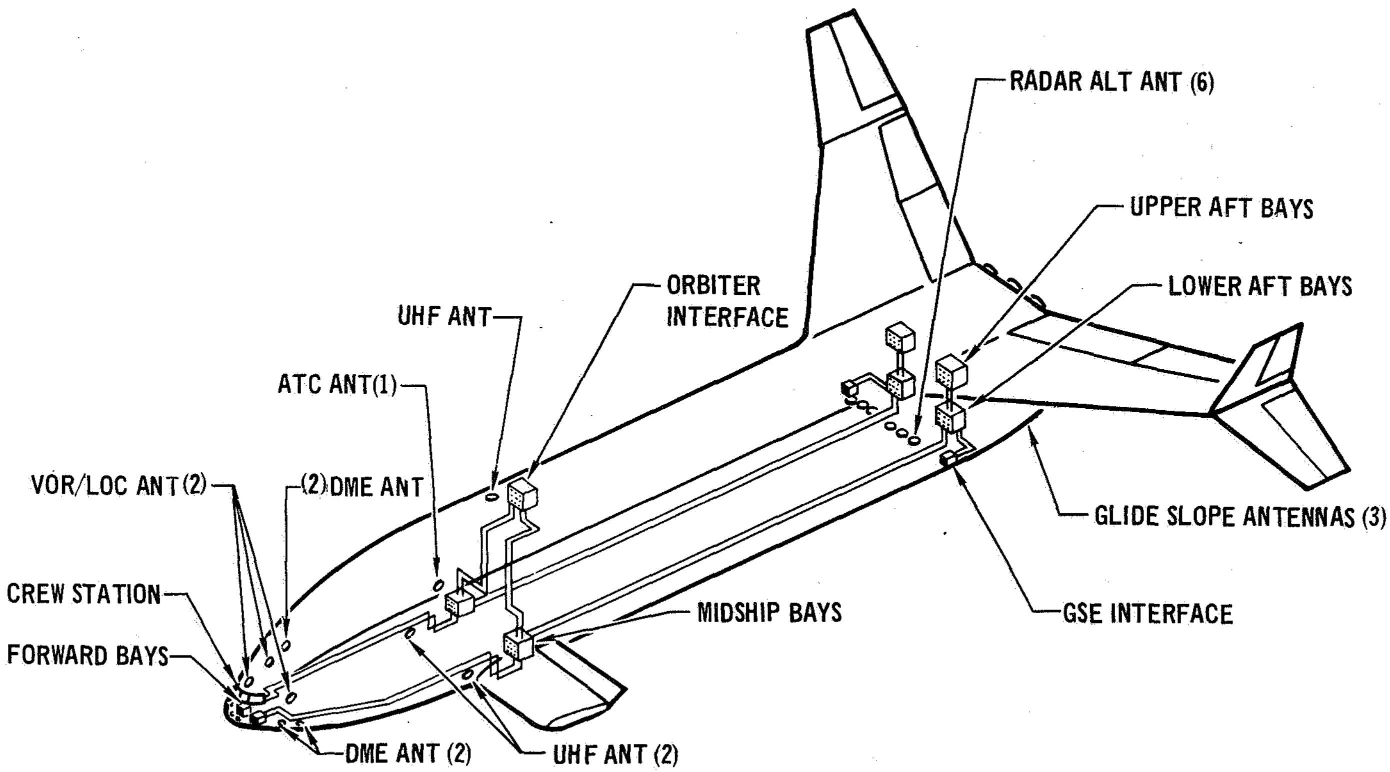


FIGURE 5.3–2

GENERAL AVIONICS TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
Qualify items to environments applicable to specific space shuttle usage.	Required to verify environmental compatibility of the item, or to support design qualification analysis, and assure crew safety and mission success.
Demonstrate subsystem performance for the spectrum of mission conditions; including operation at nominal and off nominal conditions.	Required to provide early development and verification of subsystem design and thereby reduce the risk of costly design changes at a later time in the program.
Verify functional compatibility of the subsystems with the crew and other interfacing vehicle and GSE subsystems.	These tests are required to verify vehicle system design compatibility and assure specified performance and crew safety. They are required prior to the availability of a flight vehicle, to minimize costs and risk associated with any need for major design changes encountered later in the program.
Verify functional compatibility of the avionics subsystems with their external interfaces (e.g., mission control and range facilities).	This is necessary to substantiate overall system design and to assure Space Shuttle System operational capabilities.
Demonstrate subsystem design which permits onboard and independent recognition and correction of critical malfunctions.	Required to assure design safety and thereby enhance crew safety and probability of mission success.
Integrated subsystem tests are required after installation of the LRU's and system components in the vehicle.	These tests demonstrate the proper functioning of the subsystem, the compatability of the component LRU's with each other and the vehicle cabling and environmental control systems.
Combined system tests are required following completion of the installation of interrelated systems (e.g., Comm-Navaids and DMU, DMS and Control and Display System), using vehicle electrical and mechanical interfaces.	These tests verify the interfaces between systems and the vehicle and are required for acceptance of the vehicle into the final assembly phase of manufacturing.
Overall Avionics System acceptance tests are required at the completion of final assembly, operating all subsystems with onboard checkout and control.	This test verifies the capability of the DMS to control and monitor all systems, verifies electromagnetic compatability between operating subsystems and provides baseline comparison of control and monitor parameters between initial (development test) vehicle and subsequent one.
A predelivery flight acceptance test is required on the completed vehicle, utilizing the total avionic system, propulsion and mechanical system to check proper operation of all subsystems that will operate during horizontal flight.	This acceptance test is to provide a complete functional check of all systems as a prerequisite to flight.

FIGURE 5.3–3

for the subsystem. These requirements are directed toward system design verification of performance which meets or exceeds the requirements of the vehicle CEI Specification.

5.3.1.3 Test Approach and Rationale - The baseline test approach is shown in Figure 5.3-4. Ground tests include component and LRU development, component and LRU qualification, subsystem development and integration, and avionics system integration. Acceptance tests include component tests at the vendors, factory tests, and preflight tests. Flight tests include operational verification of subsystems during horizontal and vertical (mated) flights.

Component and line replaceable unit development testing is conducted to obtain data for design analysis and to verify design approaches. Typical component development tests include high temperature antenna window transmissibility at operating frequencies, antenna patterns, gyro drift performance, and gimbal servo loop performance for the IMU. Typical LRU development tests include electromagnetic radiation and susceptability, built-in-test for malfunction detection, transient voltage protection including power interrupts, and limited service proof.

Qualification tests are conducted to support qualification of production prototype components or subassemblies of the vehicle avionics system. These tests, design analysis of development tests, and analysis of similar qualified hardware are used individually or in combination to support the contractor's recommendations as to qualification status of hardware. Details of the MDAC approach to equipment qualification is in Paragraph 4.0 of Section A of this document.

Subsystem development and integration testing is conducted early with engineering model and prototype hardware in a bench test setup to assure interface compatibility with the centralized data bus/computer data management subsystems.

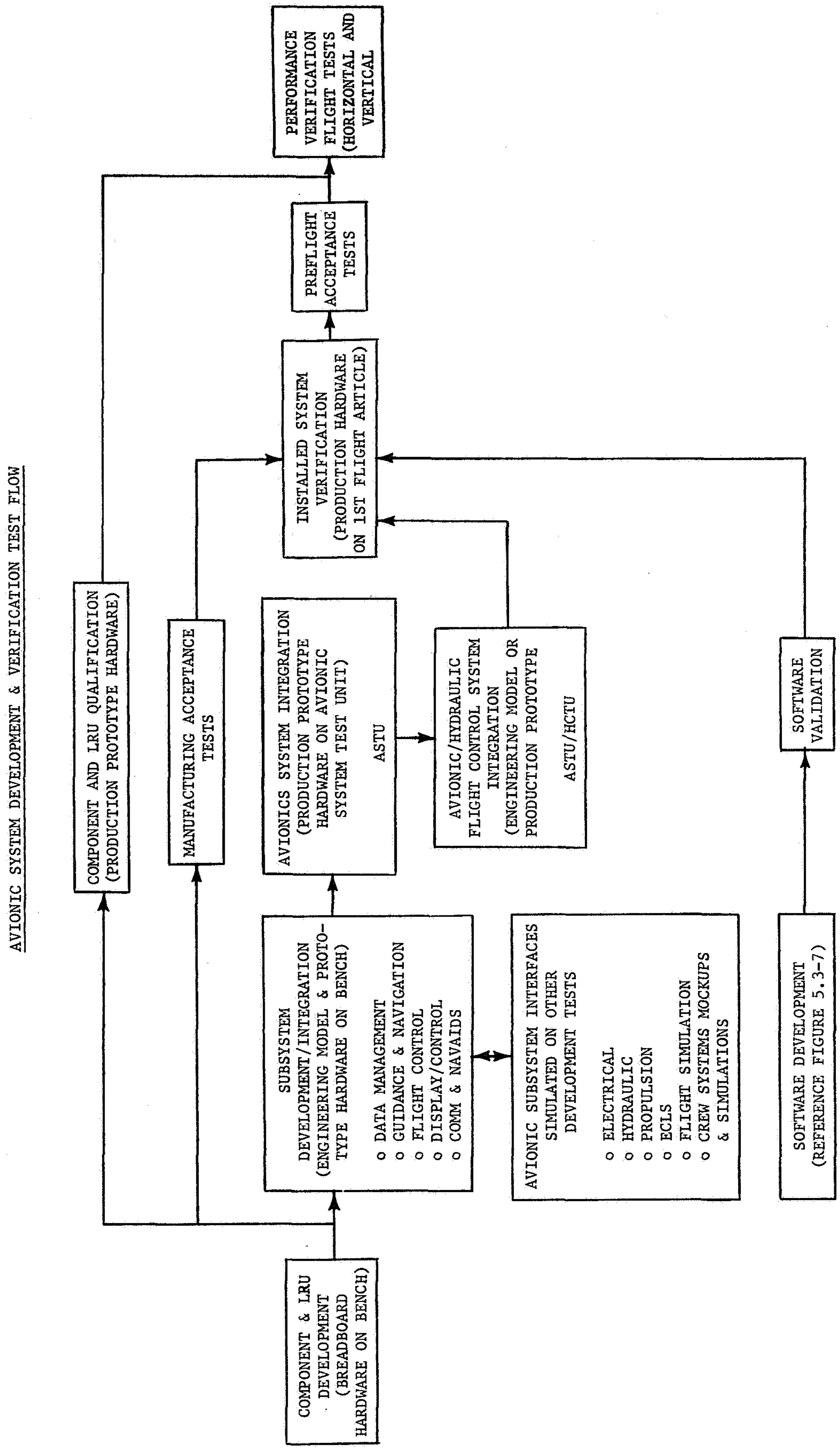

AVIONIC SYSTEM DEVELOPMENT & VERIFICATION TEST FLOW
COMPONENT & LRU DEVELOPMENT (BREADBOARD HARDWARE ON BENCH)
SUBSYSTEM DEVELOPMENT/INTEGRATION (ENGINEERING MODEL & PROTOTYPE HARDWARE ON BENCH)
o DATA MANAGEMENT
o GUIDANCE & NAVIGATION
o FLIGHT CONTROL
o DISPLAY/CONTROL
o COMM & NAVAIDS
AVIONIC SUBSYSTEM INTERFACES SIMULATED ON OTHER DEVELOPMENT TESTS
o ELECTRICAL
o HYDRAULIC
o PROPULSION
o ECLS
o FLIGHT SIMULATION
o CREW SYSTEMS MOCKUPS & SIMULATIONS
SOFTWARE DEVELOPMENT (REFERENCE FIGURE 5.3-7)
COMPONENT AND LRU QUALIFICATION (PRODUCTION PROTOTYPE HARDWARE)
MANUFACTURING ACCEPTANCE TESTS
AVIONICS SYSTEM INTEGRATION (PRODUCTION PROTOTYPE HARDWARE ON AVIONIC SYSTEM TEST UNIT)
ASTU
AVIONIC/HYDRAULIC FLIGHT CONTROL SYSTEM INTEGRATION (ENGINEERING MODEL OR PRODUCTION PROTOTYPE
ASTU/HCTU
SOFTWARE VALIDATION
INSTALLED SYSTEM VERIFICATION (PRODUCTION HARDWARE ON 1ST FLIGHT ARTICLE)
PREFLIGHT ACCEPTANCE TESTS
PERFORMANCE VERIFICATION FLIGHT TESTS (HORIZONTAL AND VERTICAL

FIGURE 5.3–4

Major subsystem activities using fully redundant hardware are envisioned for data management, flight control, guidance and navigation, and video displays. In addition to developing compatible interfaces with data management, these activities are used to develop subsystem software including a malfunction detection and checkout capability where end-to-end tests are practical or where data from several LRU's is needed. In general, these major subsystems activities are conducted in only one location for both orbiter and booster. Flight control is an exception in that orbiter and booster contractors each have a flight control setup.

Avionics system integration testing is conducted with fully redundant, qualification type hardware installed in an Avionics System Test Unit (ASTU). Paragraph 6.1 of this section describes the ASTU test programs and includes a figure of an conceptual test setup. Tests using the ASTU will verify integration of the total avionics system, including software, crew station control and displays, and GSE compatibility. The ASTU will be used to verify that the data management and computer software function as a subsystem with fail-operate, fail-operate, fail-safe capability, and that data management functions with other avionics equipment, especially the multiple redundancy capability subsystems. Integration of the electrical system and the avionics will also be tested on this unit.

Hydraulics and controls tests are supported by avionics flight control and data management equipment and test software to facilitate closed loop hydraulic flight controls system integration and development. Paragraph 6.3 of this section discusses these total flight control system tests. Other major test articles or activities which require avionics support include displays and controls for crew station simulations plus data management equipment and software for main propulsion, APU and ACPS.

Integration verification of installed systems on the first flight article includes actual interfaces with some nonavionics subsystems for the first time. Hence, the flight software associated with controlling and monitoring these subsystems will be verified. The GSE, as well as the ground and flight software associated with vehicle checkout, will be mated with the avionics system. Finally, mission flight simulations will be conducted wherein the actual flight software and vehicle systems are used and only vehicle flight is simulated. Prior to vertical (mated) flight, the orbiter-booster data transfer interfaces are verified.

The approach to acceptance testing for the avionics system is described in the following sections. Component and LRU testing of avionics components will be accomplished prior to installation in the vehicle (Reference Paragraph 5.0 of Section A).

Acceptance testing of each avionics subsystem will be conducted with the subsystem components connected to vehicle cabling, and installed at an appropriate point in the assembly flow. Interfaces with other subsystems will be simulated. The subsystem will be functionally tested in normal and redundancy modes typical of mission operating conditions, including nominal and off-nominal interface inputs. Ideally the operation of the Data Management System, central computer, data bus, digital interface units and associated software will have been verified first. If this is prevented by technical or schedule problems, an alternate is to develop data bus interface simulators to support the tests.

End-to-end testing will be employed using the on-board checkout software. Operation of BIT and malfunction detection circuitry will be verified. In the case of redundant subsystems, the computer voting and configuration management functions will be checked.

Combined systems acceptance tests will be preformed upon the completion of the installation of interrelated systems. Flight hardware will be used with vehicle cabling and environmental control to demonstrate that electrical and mechanical interfaces provide specification performance. Typical of these interfaces are Communication Navaids and IMU, DMS and Crew Station Controls and Displays, Flight Control System and Hydraulics. This test phase will be completed before the start of final assembly operations. Onboard check out capability will be used with GSE support as necessary to functionally test the systems.

An overall avionic system acceptance test will be performed on completion of final assembly operating all avionics systems with onboard checkout and control. This test demonstrates the capability of the DMS to control and monitor all systems. System performance is closely monitored for any evidence of spurious operation due to electromagnetic interference between installed systems, calbing and GSE. Parameter values observed during this test provide the initial entries in the performance data bank for the development of trend data. The vehicle will be in flight configuration with the GSE that will be used in support of flight test.

Flight tests will verify satisfactory subsystem operation, and the functional and operational interfaces of the various elements of the avionics subsystem. The interface between the Avionics and other booster subsystems, such as hydraulics, electrical, environmental control, crew, etc. will be verified. This verification will include electromagnetic compatibility (EMC) between the booster avionics and other subsystems. To facilitate this verification, the avionics system of the first horizontal test vehicle shall be as close to a production configuration as possible. It will be verified that the Development Flight Instrumentation system is compatible with the production avionics system and does not degrade subsystem operation in any respect. These verifications will be obtained, concurrently with other test objectives, by subsystem operation in all applicable modes in-flight, prior to first manned vertical flight. An inflight verification check of operational interfaces and EMC will be performed prior to committal to preparation for vertical launch.

Vertical takeoff flight operation of the Avionics subsystem will be preceded by extensive testing of functional capability in the horizontal flight test program. The primary objective of the avionics portion of the vertical test program will be the verification of satisfactory subsystems operation prior to, during, and after exposure to launch, ascent, on-orbit, entry, and transition, along with verification of the functional and operational interfaces of the various elements of the avionics subsystem among themselves and with other vehicle subsystems. This verification will include electromagnetic compatibility (EMC) between the booster avionics and other subsystems, including the mated orbiter subsystems.

Throughout the avionics development and verification test program, identical GSE is used at the vendors, MDAC, assembly and launch site. This is done to assure that support equipment requirements are fully assessed and that the equipment which is provided is compatible with the subsystems and procedures which are developed.

Figure 5.3-5 summarized the significant information on the development and verification test program. Figure 5.3-6 presents the baseline schedule of these development and verification tests.

5.3.2 Guidance and Navigation (G&N)

5.3.2.1 Subsystem Description - G&N equipment for the orbiter includes 4 inertial measurement units (IMU). Computations are performed in the data management central computers.

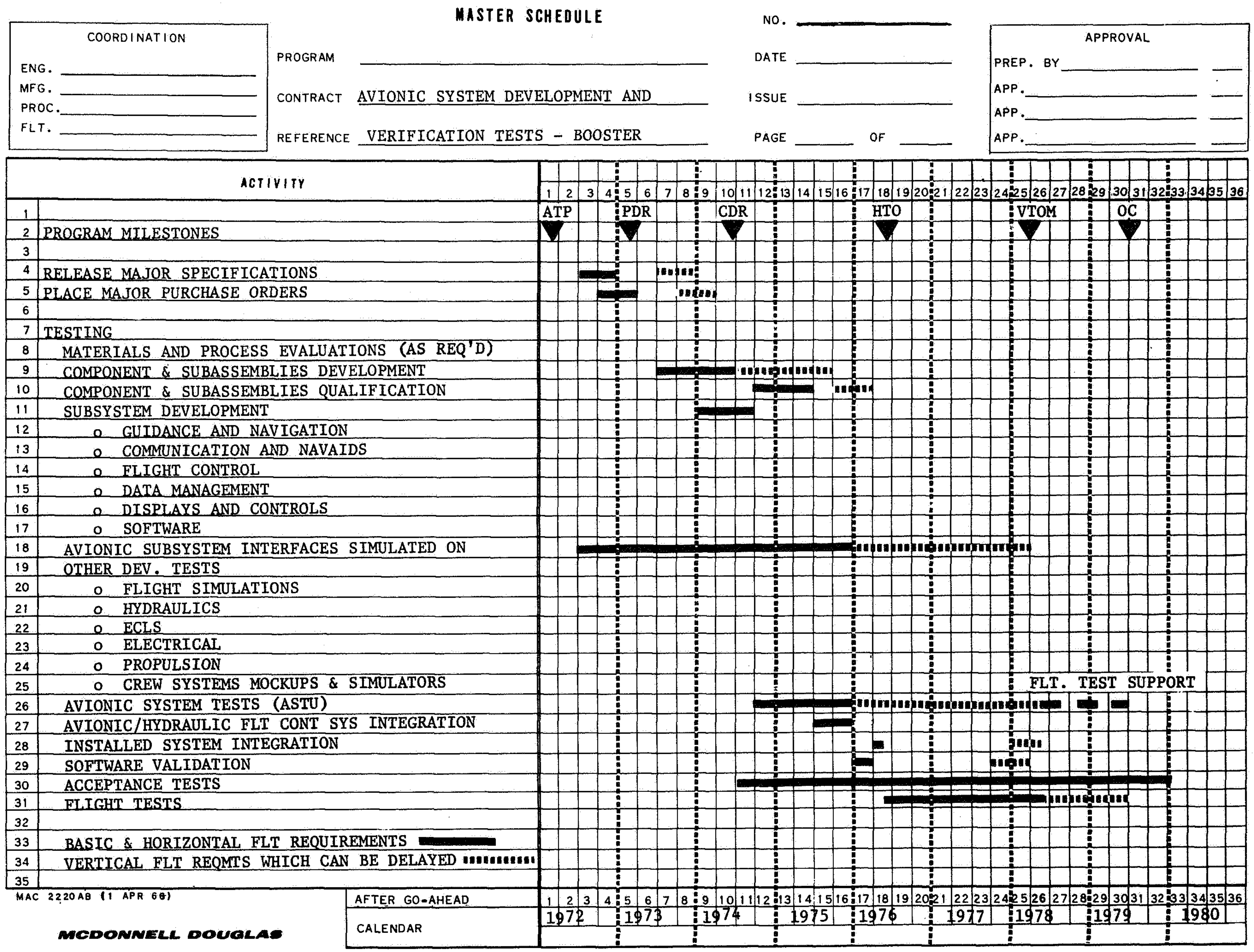
5.3.2.2 Test Requirements and Justification - In addition to those requirements in Paragraph 5.3.1.2 the following are significant to this subsystem.

AVIONIC SYSTEM DEVELOPMENT & VERIFICATION TEST SUMMARY

TESTS	REQUIREMENTS AND OBJECTIVES	APPLICABILITY		HARDWARE		FACILITY AND SET-UP
		COMMON	BOOSTER ONLY	QUANTITY	TYPE	
1. Materials and Process Evaluations	o Design information	X		As applicable	Specimens & samples	o Metallurgical & chemistry labs, machine and fabrication shops o Plasma facility o Located at MDAC & the vendors
2. Component & Major Subassemblies Development	o Design information and evaluation	X		1 each 1 each	Subassembly breadboard Engineering model	o Avionics lab including associated test support hardware, power & instrumentation o Star & horizon simulation o Antenna range and models o Commercial computer o Plasma facility at MDAC for antenna window development o Environmental simulation capabilities (EMI, dynamic, pressure, thermal, etc.) o All located at MDAC & the vendors
3. Component and Major Subassemblies Qualification	o Verification of specification	X		△1	Production prototype	o Essentially the same facilities as required above
4. Subsystem Development o *Guidance & Navigation* △2 o Communications and Navaids o Flight Control o Data Management △2 o Displays & Controls △2 o Software	o Verification of subsystem performance o *Demonstration of failure tolerance* o Verification of EMC o Verify subsystem interface o Develop procedures o Provide software development data o Assess GSE needs o Provide test software for other development testing	△2	X	Equiv. of 1 *ship set*	Engineering models & *production prototype*	o Essentially the same facilities as *required above* o Prototype GSE
5. Avionics Subsystem Interfaces Simulated on Other Development Tests o Flight Simulation o Hydraulics o ECLS o Electrical o Propulsion o Crew Systems Mockups & Simulators	o Verify interface requirements		X	As applicable	Engineering models, software and simple hardware simulations	o As applicable to the tests on which the interface is simulated
6. Avionics System Integration	o Same as in 4. above but at system level		X	1 ship set (from 4. above)	Engineering models & production prototype	o Avionics system test unit (ASTU) @ MDAC
7. Avionic/Hydraulic FCS Integration	o Same as above but for total end-to-end integrated FCS		X	Same as above plus HCTU	Same as above	o ASTU and HCTU FCS subsystems "patched" together. The setup would be at MDAC and would require operational GSE and applicable flight and checkout software.
8. Software Validation	o Verify functionality and completeness		X	Complete set	Flight & checkout	o Portions of the ASTU and a commercial computer @ MDAC
9. Installed System Integration	o System integration verification o Verification of EMC o Verification of procedures		X	1 ship set	1st production vehicle	o First flight article o Production GSE o Flight Software o Located at final assembly site (baseline KSC)
10. Acceptance Tests o Component o Subassemblies o Subsystem o Combined Subsystem	o Check functional operation o Check interface		X	3	Production vehicles	o Vendor laboratories o Vendor manufacturing facilities o Production GSE
11. Flight Tests o Horizontal Takeoff o Vertical Takeoff	o Demonstrate satisfactory inflight performance		X	3	Production vehicles	o Horizontal flight test facility @ EAFB & KSC o Vertical flight test facility @ KSC

△1 Reference the Qualification Test Plan: Paragraph 4.0 of Section A
△2 Majority Common to Orbiter and Booster

FIGURE 5.3–5


MASTER SCHEDULE
COORDINATION
ENG.
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ACTIVITY
1
2 PROGRAM MILESTONES
3
4 RELEASE MAJOR SPECIFICATIONS
5 PLACE MAJOR PURCHASE ORDERS
6
7 TESTING
8 MATERIALS AND PROCESS EVALUATIONS (AS REQ'D)
9 COMPONENT & SUBASSEMBLIES DEVELOPMENT
10 COMPONENT & SUBASSEMBLIES QUALIFICATION
11 SUBSYSTEM DEVELOPMENT
12 o GUIDANCE AND NAVIGATION
13 o COMMUNICATION AND NAVAIDS
14 o FLIGHT CONTROL
15 o DATA MANAGEMENT
16 o DISPLAYS AND CONTROLS
17 o SOFTWARE
18 AVIONIC SUBSYSTEM INTERFACES SIMULATED ON
19 OTHER DEV. TESTS
20 o FLIGHT SIMULATIONS
21 o HYDRAULICS
22 o ECLS
23 o ELECTRICAL
24 o PROPULSION
25 o CREW SYSTEMS MOCKUPS & SIMULATORS
26 AVIONIC SYSTEM TESTS (ASTU)
27 AVIONIC/HYDRAULIC FLT CONT SYS INTEGRATION
28 INSTALLED SYSTEM INTEGRATION
29 SOFTWARE VALIDATION
30 ACCEPTANCE TESTS
31 FLIGHT TESTS
32
33 BASIC & HORIZONTAL FLT REQUIREMENTS
34 VERTICAL FLT REQMTS WHICH CAN BE DELAYED
35
ATP
PDR
CDR
HTO
VTOM
OC
FLT. TEST SUPPORT
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
AFTER GO-AHEAD
CALENDAR
1972
1973
1974
1975
1976
1977
1978
1979
1980
MAC 2220AB (1 APR 66)
MCDONNELL DOUGLAS

FIGURE 5.3–6

REQUIREMENT	JUSTIFICATION
Verify the performance of the guidance and navigation subsystem (e.g., range, accuracy, etc.).	Required to validate design.
Acceptance test of the installed subsystem will be required.	Mechanical alignment of the IMU to the vehicle structure must be verified. These tests will also verify the interfaces between components and vehicle cabling.
Combined system acceptance tests are required when the vehicle assembly is complete.	These tests utilize the onboard checkout software, comm-navaids inputs, and system BIT to check IMU calibration, scale factor, null shift and drift. The tests also demonstrate the ability of the system BIT to detect malfunction and make correct indications to the crew.

5.3.2.3 Test Approach and Rationale - In addition to the normal sensor development tests, such as performance evaluation of gyros, accelerometers, and servo-loops, the IMU may need to undergo sled tests if not already done on another program. A significant integration activity is to verify IMU, installation/ alignment on the navigation bases. Other integration activities include built-in-test failure detection verifications and reconfiguration logic tests where the central computer performs failure detection and switchover.

Both ground and flight tests (both horizontal and vertical) are used to verify G&N software including area navigation and terminal landing as well as ascent and entry operations.

Installed subsystem acceptance tests will be conducted when the components of the subsystem are installed in the vehicle on structural mounting reference points and are connected to vehicle cabling. On initial installation checks, the alignment of the navigation base to the vehicle structure will be determined for future use in determining possible need for realignment after a number of flights. The subsystem will be powered via vehicle bus. The data management system (DMS) will be operative and will be used to provide onboard checkout software program to test the Guidance and Navigation system, simulate malfunctions and perform redundancy management. The IMU gyrocompassing function will be exercised and the results compared with those obtained during the LRU acceptance tests.

Combined system acceptance tests will be performed upon completion of final assembly and will involve the Guidance and Navigation subsystem and its interfaces with the Comm-navaids subsystem, DMS, and the electrical power system. The tests will be conducted using on-board checkout software. The IMU gyrocompassing and self-check features will be exercised. The voting logic of the DMS and its redundancy switching capability will be verified. The interface with the Comm-navaids subsystem will be checked by inserting simulated position update information and observing the response of the system.

Horizontal flight testing of the guidance and navigation will primarily consist of verifying the performance and accuracy of the inertial measurement units (IMU) in an installed environment. Alignment and updating capabilities will be evaluated. Redundancy switching capabilities and effects will be verified. The absence of vehicle attitude effects will be verified, as far as possible in airplane flight. The proper functioning of the interfaces between the IMU, central computer, and the flight control system, and the control and display subsystems will be verified in a flight environment. Use of the ground tracking network at EAFB to provide space positioning will be required for the system accuracy evaluation.

The vertical flight test program will expand the verification of the performance and accuracy of the inertial measurement units (IMU's). Alignment and updating capabilities of the IMU's will be evaluated. Redundancy switching capabilities and effects will be verified. The ability to provide accurate vehicle attitude, rate, velocity, and position data under all flight conditions will be verified. The proper functioning of interfaces between the IMU, the data bus, the central computer, and the flight controls and control and display subsystems will be verified during launch, ascent, entry, transition, and landing.

5.3.3 Communications and Navaids

5.3.3.1 Subsystem Description - Communications equipment for the booster includes 3 UHF sets and several intercom stations. Navaid equipment includes 3 DME sets, 3 VOR sets, 3 radar altimeter sets, and 3 ILS sets. Each equipment set includes appropriate antennas.

5.3.3.2 Test Requirements and Justification - In addition to those requirements in Paragraph 5.3.1.2 the following are significant to this system.

REQUIREMENT	JUSTIFICATION
Verify the performance limits of the communication and navigation aids subsystems (e.g., range, accuracy, etc.).	Required to validate subsystem design thereby minimizing operational risks.
Verify that antenna locations do not constrain vehicle attitude during operations.	Required to assure optimum operational flexibility.
Acceptance tests of the installed subsystem are required.	This series of tests are required to verify interfaces between the subsystem and the vehicle cabling interface.
Combined system acceptance tests of the Comm-Navaids subsystem are required when the vehicle is completely assembled.	These tests verify the control and monitor functions between the DMS and this system. The compatibility of the comm-navaid outputs with the G/N system, and the ability of the IMS to interpret BIT indications of malfunctions and take appropriate action with the selection of a redundancy.

5.3.3.3 Test Approach and Rationale - Since many of the antennas are on the vehicle bottom and must operate during aerocruise after exposure to entry thermal effects, emphasis is placed on antenna development. Screening tests are conducted to evaluate promising window materials. Integration testing of the antenna, window, and vehicle structure are conducted to verify the design. Antenna pattern tests are conducted using vehicle scale models (partial or complete sections) and pattern analysis performed for each antenna to verify that antenna patterns and locations do not constrain vehicle attitude during operations.

Special attention is required for the DME equipment to assure adequate navigation accuracy during the terminal approach and landing phases to provide an automatic landing capability. The DME equipment must be compatible with conventional VORTAC ground stations for ferry flights and normal VFR landing as well as precision DME ground stations for automatic landings.

Horizontal flight tests are used to validate performance of the navigation software, navaid equipment, and ground equipment planned for the operational phase.

Installed subsystem acceptance tests will be performed after the components are installed in the vehicle and will use vehicle cabling, DMS and environmental control system. The onboard checkout software will be used together with open loop reception of local navigational services (or simulation by small portable generators) to perform end-to-end checks of each link and demonstrate the redundancy switching capability of the DMS. The intercom system will be checked in its various operating modes and interfaces (vehicle to ground, inter-vehicular etc.). The system will be observed for any indications of spurious operation that might be caused by electromagnetic interference.

Upon completion of final assembly of the vehicle the comm-navaids system will be subjected to a combined systems test to demonstrate proper functioning with the G&N system, crew station, DMS and the BIT indications of malfunction aid equipment switching. The test will use the onboard checkout software, and simulation generators where required. System parameters will be recorded to establish the initial points for future trend analysis. All control and monitoring functions will be checked to determine flight readiness of the vehicle. The communications and navaids testing in the horizontal flight mode will be primarily concerned with verifying the installed accuracy and range of the navaids (VOR, DME, ILS) and the radar altimeter. Ground tracking for comparison of actual vehicle position and altitude versus indicated values will be required. The effects of altitude rate of change, flight attitude, and configuration on system performance will be evaluated.

Antenna coverage for all subsystems will be evaluated inflight to correlated with ground test and design data, and aid in system performance verification. Redundancy switching capabilities and effects will be verified.

The operation of the UHF communication and crew intercom systems will be verified concurrently with other horizontal flight test objectives. The proper functioning of the interfaces between the communication and navaid subsystems, with the data bus and the control and display subsystems will be verified in the horizontal flight environment.

The operation of the communications and navaids in the operational landing area at KSC will be flight check-verified, prior to the first manned vertical launch.

The satisfactory operation of the UHF communication, and crew intercom systems (both internal and between mated vehicles) will be evaluated and verified concurrently with other vertical flight test objectives. Signal strengths and vehicle attitude effects will be evaluated in flight and correlated with horizontal flight test, ground test, and design data. The proper functioning of the interfaces with the control and display subsystems during and after exposure to entry will be verified. The proper functioning, accuracy, and range of the approach and landing navaids (VOR, DME, ILS) and the radar altimeters after exposure to the full mission environment will be obtained by comparing their performance with that observed in the horizontal airplane flight test program.

5.3.4 Flight Control Avionics

5.3.4.1 Subsystem Description - Flight control avionics equipment for the Booster includes two different electronic packages and four different sensor packages. The actuator electronics provides control of surface actuators and thrust vector control actuators while the thruster electronics provides control of reaction jet engines. Sensors which are used during atmospheric flight include a 3-axis rate gyro package, a 2-axis accelerometer package, a static pressure sensor, and total temperature/pressure sensors. Attitude reference data is provided by the G&N IMU during all flight phases. All computations are performed by the data management central computer. All flight control equipment including the IMU and central computer is quad-redundant.

5.3.4.2 Test Requirements and Justification - In addition to those requirements in Paragraph 5.3.1.2 the following are significant to this subsystem.

REQUIREMENT	JUSTIFICATION
Demonstrate crew-initiated override/interrupt capability for critical control functions.	This is necessary to assure flight safety.
An acceptance test of the installed system will be required at the vehicle assembly point.	This test is required to verify the compatibility of the FCS components (electronic) with the mechanical systems they interface and the vehicle's cabling and environmental control system.
Combined systems tests utilizing low level hydraulic power will be required after final assembly.	These tests are required to demonstrate that the air data system is operating and the correct operation of mechanical linkages with simulated signals applied to the data bus and FCS. Simulated signals on the data bus will also be used to torque the FCS gyros to check response time.

5.3.4.3 Test Approach and Rationale - Development of the flight control equipment includes demonstration of built-in-test and voting capability. Rate gyros and the IMU are tested on a motion table. Closed loop testing of control surface and TVC actuator interfaces takes place on the Hydraulics and Controls Test Unit (HCTU) whereas ACS testing is a separate test with the ACPS Test Unit.

Subsystem acceptance tests will be conducted with the subsystem components connected to vehicle cabling and hydraulic lines when the vehicle is in the final assembly area. Where necessary, interfaces with other subsystems will be simulated. The subsystem will be functionally tested to the extent possible with ground hydraulic power. Data bus control and monitoring of the subsystem will be checked.

Prior to rollout from final assembly, a combined system acceptance test will be performed. All interfacing systems will be connected. The onboard checkout program will be used to conduct the test. Low level ground hydraulic power will be used. The performance of the air data system and response of SAS and mechanical linkages will be checked with simulated signals applied to the data bus and FCS. The response time of gyros in the FCS system will be checked.

Horizontal flight testing of the flight control system is accomplished during the flight characteristics stability and control testing. Flying qualities will be similarly evaluated for the various autopilot modes: angle of attack, altitude hold, and heading hold. The vehicle's ability to maintain angle of attack, altitude, or heading within acceptable limits will be verified. The velocity control auto-throttle and speed brake capability will be verified. Autopilot operation will be evaluated over the airplane flight velocity range at several altitudes. The effects of gross weight, center of gravity, configuration changes and redundancy switching will be included.

The accurate operation of the air data sensors and electronics will be verified. This testing will interface with the static source calibration flying described in paragraph 4.3.

The automatic approach and landing function of the subsystem will be developed and verified during the latter part of the horizontal flight program, at the primary operational site, KSC, utilizing the actual installed, operational landing navaids prior to vertical flights.

The proper functioning of the flight control subsystem with the data bus, the central computer, the control and display avionic subsystems, the airbreathing engine controls, and the aerodynamic control surface actuators (rudder, and elevons) will be verified by actual operations during the horizontal flight test program.

The majority of the autopilot mode testing and automatic approach and landing testing will be complete prior to first manned orbital flight.

5.3.5 Data Management and Control

5.3.5.1 Subsystem Description - Data management equipment for the Orbiter and Booster is identical and includes four central computers, a system control unit (SCU), two mass memory units, two maintenance recorders, four data busses, and 40 to 50 Digital Interface Units (DIU's). This equipment performs onboard computation, data acquisition and distribution, and data storage for all vehicle subsystems.

5.3.5.2 Test Requirements and Justification - Additional test requirements which are significant to the subsystem are as follows:

REQUIREMENT	JUSTIFICATION
Verify that the data subsystem does provide self-validation and error protection.	To assure a protection against erroneous data for flight safety.
Verify computer redundancy management capability.	Required to meet "fail-operate, fail-operate, fail-safe" requirement.
Subsystem checkout and integration tests are required for acceptance	These tests are performed to demonstrate that the system operates properly with the interfacing DIU's and can perform the required redundant system control. GSE monitoring performed at special GSE connectors is used to check test parameters that are not available in normal operation. These tests will verify the ability of the BIT to detect and isolate malfunctions in the system.
Combined system tests are required to verify operation of the control and monitoring functions of the DMS with all interfacing subsystems when vehicle assemble is completed.	These tests, which make full utilization of the computer software directed tests and BIT, demonstrate the autonomous operation of the system and develop confidence in the flight readiness of the vehicle.

5.3.5.3 Test Approach and Rationale - Central computer redundancy, data bus, and inflight memory load operations are internal to data management and can be verified independent of other subsystems using fully redundant hardware in a bench setup. The DIU's provide the interface with other subsystems and verification is accomplished while operating with these subsystems.

Redundant Computer operation is new for the shuttle design and will receive significant attention. Computer redundancy tests include verification of synchronization, data voting, malfunction detection, and initialization. Essentially synchronized operation is necessary during critical phases such as ascent and entry when all four computers are powered-up and performing identical functions. The SCU provides the computers with synchronization signals. During these phases, each computer receives the same input data from redundant subsystems. This redundant subsystem input data is voted by each computer which selects what it believes is the correct input data. If all computers made the correct selection of input data and all internal computer operations are correct, all output data should compare bit by bit. This comparison is made by the input/output sections of computers which then provides the switching signal from a failed computer to an operational computer. During noncritical phases such as orbital coast, only two computers are powered and performing functions. Hence, each computer is programmed to detect failures (with the aid of some built-in-test) within data management and isolate the failure to the DIU, bus, or input/output control unit level for the purpose of switching out failed units. When additional computers are first powered up, each computer must be initialized with data from the computer already up.

Bus operation is also new for the Booster. The bus is designed to have a specified signal to noise ratio and to detect and eliminate the effects of bit errors which do occur using horizontal and vertical odd parity concepts. Verification of an acceptable bit error rate and the ability to detect and eliminate errors will be demonstrated.

Although inflight memory load has been performed in the past, special verification of the load concept is required due to the requirement of no loaded bit errors. This verification is similar to the bus, i.e., proof of an acceptable bit error rate from the mass memory and bit error detection and elimination by the computer before it stores data in its memory.

Following demonstration of the internal data management operations, the subsystem equipments including DIU's are used for interfacing with other vehicle subsystems.

When the components of the DMS have been installed in the vehicle, a series of tests will be conducted to verify the interfaces with the several data buses and many DIU's. The onboard checkout software program will be loaded in the computer.

A roll call and echo routine will verify response from the DIU's, simulated malfunctions will be introduced to determine that the IOCU and SCU will perform their malfunction detection and correction roles. The capability to load and unload programs from Mass Memory will be verified. The auto/manual switchover function of the SCU will be verified. Upon completion of this series of tests the DIU's will be connected to the systems they service and the DMS will be available to support installed system acceptance tests of other subsystems.

When vehicle assembly is complete and all interfacing systems have been connected to the DMS (Data Management System) a combined system test will be conducted. The test will use the onboard checkout program to verify response from all DIU's. Simulated malfunctions will be initiated to cause the BIT in various subsystems to call for redundancy switching by the DMS and for status display on the Caution and Warning system. Data bus failures will be simulated to demonstrate the failure detection and correction capability of the system. All control and monitor functions involving the DMS should be checked during this test to determine that the vehicle and DMS are flight ready.

The highest confidence level in the proper operation of the data management subsystem and its components - (the data bus, central computer, and system control unit) exist just after performing a mission. This is due to operating the quad-redundant system in the mission environment and comparing the operation of each data management subsystem bit by bit in real time.

The horizontal flight test is viewed as the most thorough absolute test of the data management subsystem operation possible before it is relied upon as a flight safety subsystem during the time critical vertical launch phase. During horizontal cruise flight testing, the quad-redundant data management subsystem can be switched both automatically and manually because of the non-time-critical nature of cruise flying. This flexibility permits a thorough evaluation of data management subsystem operation including single point failure effects, i.e., the command pilot could fly the airplane with one system while the pilot performs diagnostic and switching functions using the remaining systems. For example, if improper system control unit operation occurs, the pilot could perform manual computer switching. If software bugs are suspected, the pilot could reload the computer program and re-initialize the system. This manual switching, memory reload, initialization, and other aspects of data management operation will be evaluated and verified concurrently with other objectives during horizontal flights where proper real time operation is not as flight critical as during vertical flights.

Operation of the data subsystem and its components (the data bus, the central computer, and system control unit) in the vertical flight environment will be verified concurrently with other vertical test objectives. Satisfactory identification, storage, and use of data will be verified.

5.3.6 Displays and Controls

5.3.6.1 Subsystem Description - The controls and displays are the crew-to-vehicle subsystems interface. They include three multipurpose Cathode Ray Tube (CRT) displays with associated symbol generators and camera microviewer assemblies; three keyboard assemblies; dual (2) flight control displays and controls, i.e., electromechanical attitude director indicators, center control sticks, rudder/brake/nose wheel steering pedals, attitude side arm controller, and flight data dials; and numerous vertical scale indicators, lighted push button switches and subsystem management panels. This equipment is located in the main instrument panel, a left outboard console, a right outboard console, a center console, the floor area and an overhead panel.

5.3.6.2 Test Requirement and Justification - There are no test requirements for this subsystem, beyond those which were listed in Paragraph 5.3.1.2.

5.3.6.3 Test Approach and Rationale - The crew station displays and controls design evolves through use of analysis, models, equipment design, integration testing using cabin mockups with prototype equipment, and flight simulations. Equipment is designed and evaluated for compatibility with the human engineering aspects of visibility, feel, touch, temperature, moisture proof, noise generation, and safety including hazards due to glass breakage, high voltage arcing and implosion/exposions. The crew station is designed and evaluated for adequacy of illumination, work space, operability and accessability. Paragraph 5.4.2, Crew Systems, includes additional information as to what simulators and mockups will be available for these tests and evaluations.

Special tests of the CRT display equipment are conducted to demonstrate adequate phospher life and persistance, TV line resolution and stability, brightness/contrast/grey shades, frame rate, symbol and computer data registration accuracy and stability, symbol size and writing speed, film loading, and low noise generation.

Integration testing of the major display and control equipment with the computer/data/bus/DIU equipment is conducted on the Avionics System Test Unit (ASTU). Man/machine requirements including computer addressing, override and control are also conducted on the ASTU as well as on the crew station mockups,the flight simulator and the Hydraulics and Control Test Unit. Brightness/contrast/ registration testing is conducted in an integral lighting cockpit mockup.

Fixed base simulations are conducted to gain pilot acceptance of the crew station display and control design.

Acceptance testing to verify proper functioning of CRT displays, format generators, and cockpit controls will be accomplished by exercise of the onboard checkout program. The proper operations of the controls and displays will be checked as an integral part of subsystem and combined subsystem testing.

The functional operation of the avionics controls and displays in the horizontal flight envelope will be verified concurrently with other flight test activities.

The proper functioning of the displays and controls with the central computer, data bus, and other Orbiter subsystems in the horizontal airplane flight mode will be verified by actual operation.

The accuracy and legibility of displayed information will be evaluated during the high 'g' and vibration environment of ascent, entry, and transition. Horizontal flight testing will have verified the approach and landing suitability of the system, and this will be confirmed by the vertical takeoff tests.

5.3.7 Software

5.3.7.1 Software Description - Three levels of avionics system software have been identified to satisfy the diverse requirements of subsystem development testing, avionics system integrated testing, combined systems tests with equipment installed in the vehicle, other major ground test articles as well as flight test. The three levels of software are:

(1) ground test software program,

(2) horizontal flight software program, and

(3) the total mission software program.

The ground test software program will contain the software that will provide the basic avionics system functions plus specific software test modules to satisfy the need of the individual test activities. The horizontal flight program and total mission software program will be built upon the system software and the appropriate subsystem test capabilities proven for the ground test program. In addition to the on-board type software, simulation and support software will be developed to provide realistic operational conditions for the equipment tests and to analyze and verify test results.

5.3.7.2 Test Requirements and Justification - The software task is defined to include those activities attendant with the design and production of a computer operational program. The enumeration of the software task elements are:

(1) integration of the computational requirements defined by the subsystem and technological disciplines,

(2) functional design and verification of the program,

(3) implementation processes of coding, assembly, and verification,

(4) the performance of closed-loop hardware/software validation testing,

(5) development of the software tools (assemblers/compliers, simulators, tape generation programs, etc.), and

(6) documentation describing the operational program and its utilization.

5.3.7.3 Test Approach and Rationale - The software development flow is illustrated in Figure 5.3-7. The task elements reflect the development of a flight (on-board) program, but are applicable to other forms of computer programs, e.g., ground support programs. The difference between the nonflight and flight programs is the degree of effort expended for a particular task element.

As part of the development cycle, software verification is accomplished through various levels of simulation (scientific and interpretive) and combined hardware/ software testing as well as manual audits and desk analyses. The scientific and interpretive simulations are all digital representations of the total vehicle and avionics system on a mission phase basis. The scientific simulations will be used to verify that the integration of the various input requirements has been accomplished correctly and to provide reference data for the interpretive simulation. The interpretive simulation is a basic software tool and provides the means to accomplish program debug of the coded program and to perform another level of program verification. In addition, a software laboratory including portions of the data management hardware will be used in conjunction with the all-digital

SOFTWARE DEVELOPMENT FLOW – BLOCK DIAGRAM

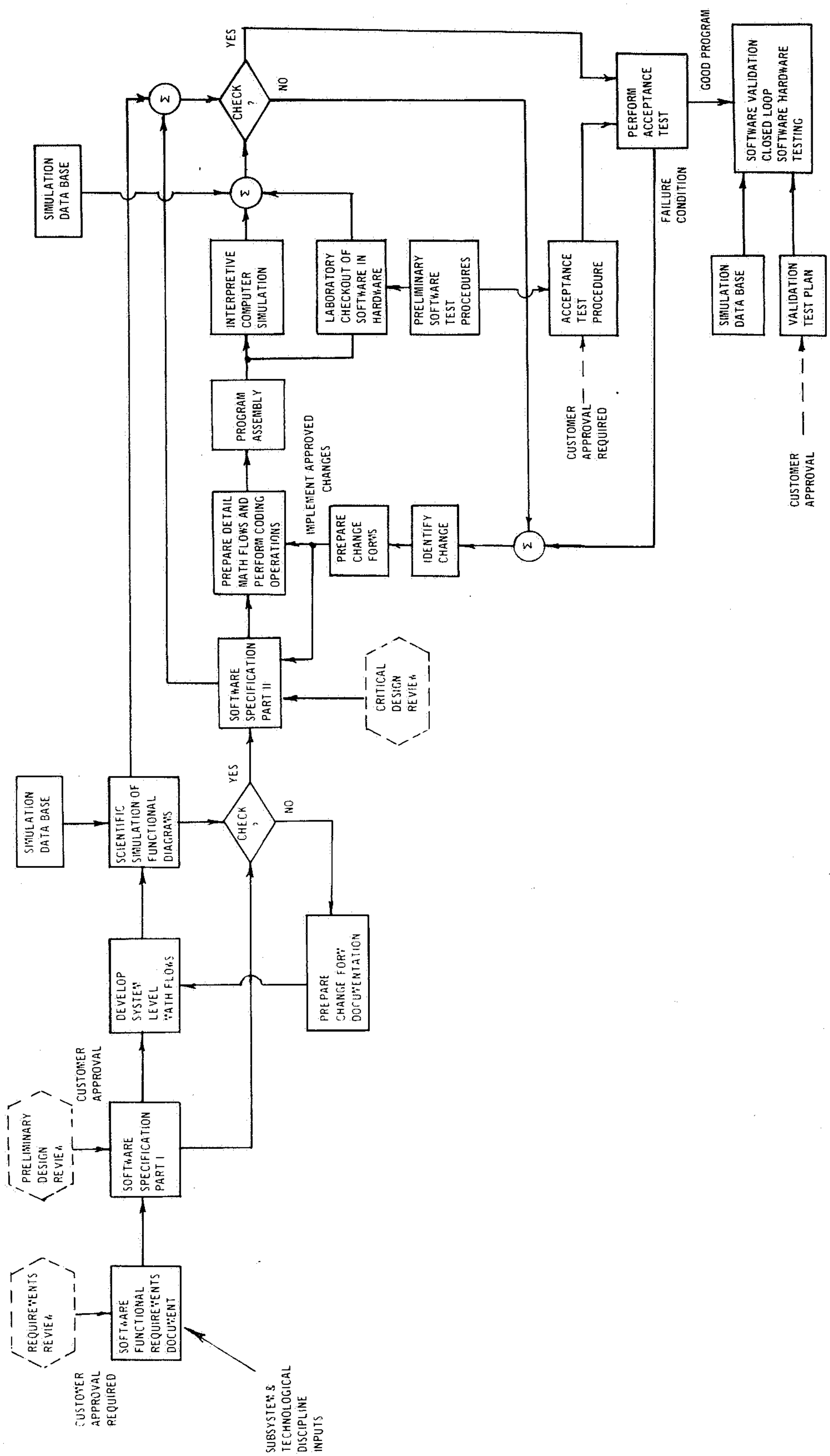


FIGURE 5.3–7

simulations to further the verification of the software and to establish, within the laboratory capabilities, that the software is compatible with the hardware. Software acceptance testing will be performed using the software laboratory capabilities and customer approved test procedures. Software validation will be accomplished using a closed loop hardware/software test facility as described in Paragraph 6.2.

5.4 Crew Station Group

5.4.1 Environmental Control and Life Support System

5.4.1.1 System Description - The Booster Environmental Control and Life Support (ECLS) subsystem provides for crew life support, and thermal control of equipment and habitable areas for all mission phases. The ECLS is comprised of the following subsystems: cabin air, cabin cooling, water supply, emergency oxygen, and equipment cooling. This section will also consider the fire extinguishing, and fog and rain removal subsystems. (Ref Figures 5.4-1 and 5.4-2)

Cabin air pressure is maintained by redundant pressure regulators which control make-up atmosphere from dedicated high pressure O_2 and N_2 supply tanks.

Emergency O_2 is supplied from a separate high pressure storage vessel. Control of CO_2, trace contaminants, and humidity is provided by a "purge" system.

The cabin cooling is maintained passively during ascent/reentry and during cruise and ferry by redundant air cycle refrigeration packages. These packages are supplied by the cruise engine compressor bleed air. Active thermal control of the liquid-cooled equipment is provided by a heat transfer loop which rejects heat to a cryogenic hydrogen heat exchanger.

Water is provided by portable carry-on containers and the fire extinguisher is a portable CO_2 type.

5.4.1.2 Test Requirements and Justification - The ECLS test requirements are delineated in Figure 5.4-3. These are directed toward system design verification of performance which meets or exceeds the requirements of the vehicle CEI Specification.

5.4.1.3 Test Approach and Rationale - The MDAC baseline approach (see Figure 5.4-4) is that components, LRU's, and major subassemblies of the ECLS subsystem are subcontracted. The subcontractors will design, develop and qualify these elements to MDAC specifications using MDAC approved procedures. Design information

BOOSTER ECLS FUNCTIONAL DIAGRAM

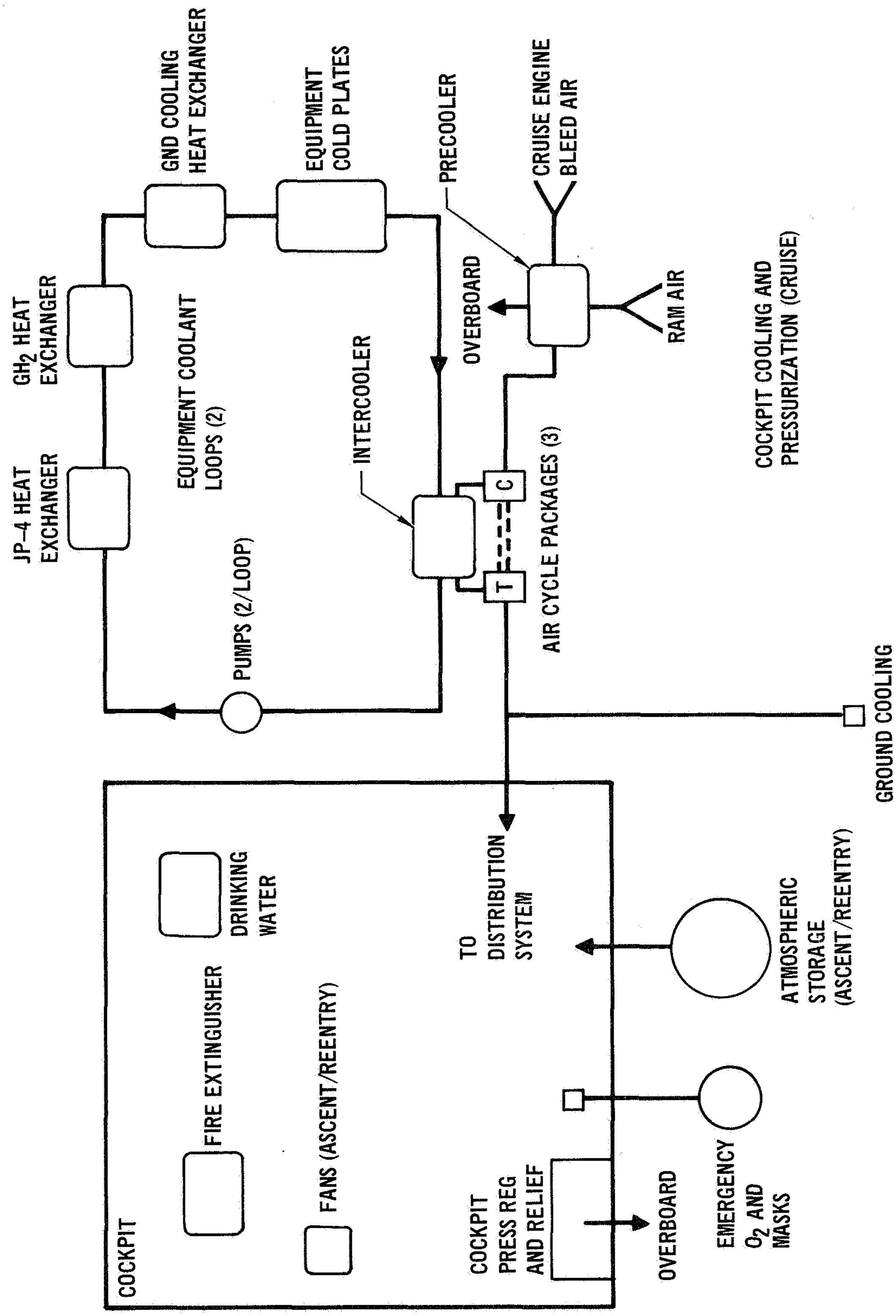


FIGURE 5.4-1

BOOSTER ECLS ARRANGEMENT

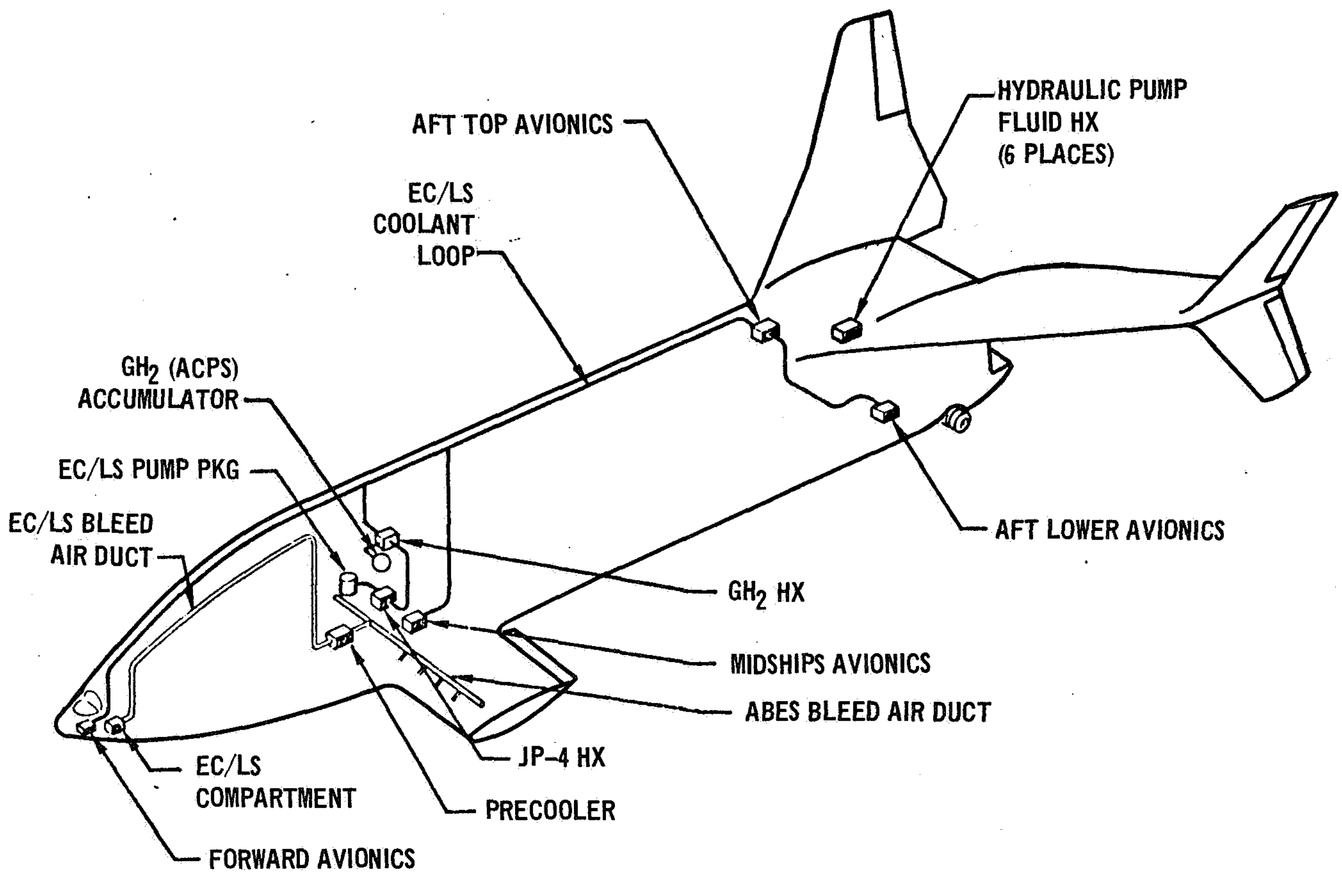


FIGURE 5.4–2

ENVIRONMENTAL CONTROL AND
LIFE SUPPORT SYSTEM TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
Qualify equipment to environment applicable to specific Space Shuttle usage.	Required to verify environmental compatibility of the item or to support design qualification analysis, and to assure crew safety and mission success.
Verify the functional design and performance of the ECLS under normal and off nominal conditions.	Required to assure design completeness and performance prior to flight usage. Also minimizes potential risk and associated costs of changes late in the development program; and, enhances crew safety and probability of mission success during the flight test program.
Demonstrate subsystem failure tolerance.	
Verify subsystem EMC.	
Verify functional compatibility of the ECLS with the crew and other interfacing vehicle and GSE subsystems.	
Identify boundries of thermal control, both high and low heat loads in conjunction with various vehicle attitudes.	
Verify fatigue life of ECLS pressure tanks.	
Check satisfactory component and subsystem assembly, installation and functional operations after manufacturing.	Required to verify that components, and subsystems as manufactured and as installed in the vehicle have been properly assembled, and will perform function within design specifications.
Demonstrate satisfactory inflight subsystem performance during all mission phases.	Required for final verification of subsystem performance.

FIGURE 5.4–3

BOOSTER ECLS SYSTEM DEVELOPMENT & VERIFICATION TEST FLOW

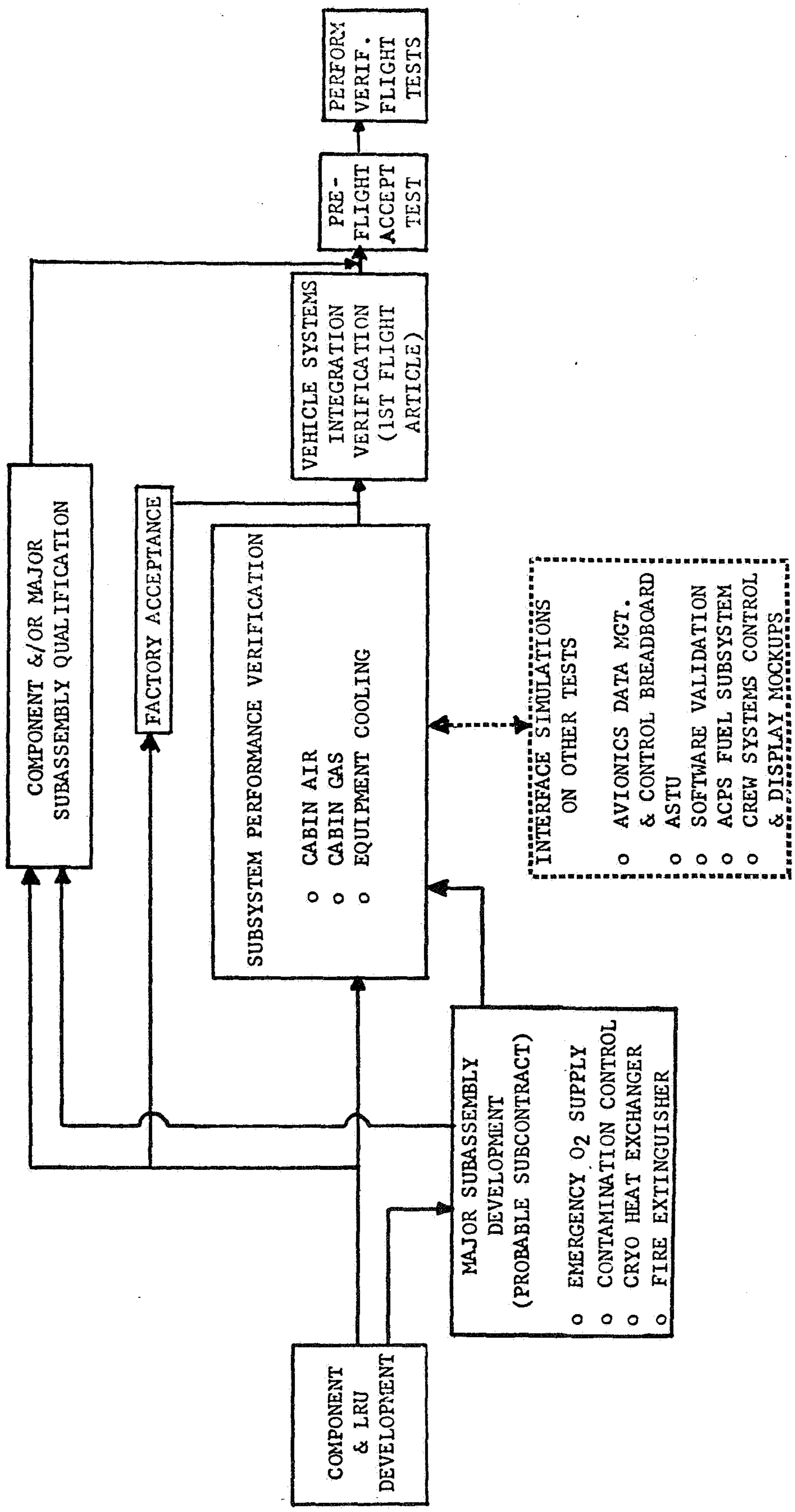


FIGURE 5.4–4

and component development tests are conducted in support of design analysis and to verify design approaches. Much of the testing is accomplished by subcontractors responsible for components and major subassemblies to demonstrate that MDAC design requirements are met. Particular emphasis is placed on selection of a water inhibiter which is compatible with the subsystem, and development of a cryogenic heat exchanger with adequate control response that does not subject the system to extremely low temperature. Also of significance is the development of atmospheric storage tanks which meet a 10 year life requirement. These tests are conducted with engineering prototype ECLS hardware and simulated environmental and subsystem interfaces. Tests will evaluate leakage, line flows, heat transfer, control response, service needs, duty cycle, and electromagnetic compatibility. The equipment mounting cold rails and cold plates are designed and developed by MDAC. Heat transfer and structural integrity testing of these items is conducted in the MDAC laboratories.

Qualification tests are conducted to support qualification of production prototype components or subassemblies of the vehicle ECLS system. These tests, design analysis of development tests, and analysis of similar qualified hardware are used individually or in combination to support the contractor's recommendations as to qualification status of hardware. Details of the MDAC approach to equipment qualification is in Paragraph 4.0 of the first section of this document.

ECLS functions (e.g., cabin pressure control, cabin air mixture and contamination control, emergency oxygen provisions, and cabin and equipment thermal control) in the flight regimes other than those encountered in sub-orbital flight are verified by cabin/airlock structural pressure/leak tests, closed loop subsystem breadboard tests and horizontal flight tests. Those system functions which require "space simulation" for performance verification are tested in thermal vacuum facilities. In lieu of a single ECLS test unit a breadboard test setup is made for each of the subsystems. These units can be assembled into an ECLS.

system test bed and used for technology advancement testing. The subsystem breadboard test setups will consist of an assembly of production prototype hardware. Production type air ducts are used in these tests. Pertinent subsystem interfaces are simulated. The environmental loads are mission-time varied, and simulated subsystem interfaces are considered for both nominal and controlled off-nominal inputs.

Functional tests on these subsystem breadboards evaluate leakage, line and duct pressure and velocity, acoustic levels, heat transfer rates, control response, subsystem/component functional compatibility, service requirements and procedures, line proof and design limit pressure levels, and duct proof pressure. These evaluations are conducted for normal operation and for inputted subsystem failure conditions, with nominal and off-nominal interface conditions. Major subsystem interfaces which are simulated on these tests are: electrical (power), hydraulic (heat load), avionic (heat loads, data management and control functions via test software and a commercial computer) and cryogenic and gas supplies.

Environmental control and life support systems integration verification tests are conducted on the first assembled flight vehicle. They include EMC tests, system response tests, functional tests of the air distribution system to verify adequate delivery to all parts of the system, sound level measurement in the habitable vehicle areas, evaluation of nominal and off-nominal system operation with normal and programmed interface failures, evaluation of heat transfer efficiency, installed duct proof pressure tests, and tests to evaluate complete system servicing needs, adequacy of procedures, and GSE. Acoustic evaluations also include the effects of all other installed systems during operation. Objectionable noise levels, if there are any, are to be minimized within the limits of safe functional performance of the subsystems.

This ECLS ground development test approach is possible with minimum risk due to the degraded performance rather than catastrophic, failure mode of the MDAC system design approach and the comprehensive flight test program which precedes the operational programs.

Since the fire extinguishing system baseline is an off-the-shelf portable CO_2 extinguisher, only equipment qualification to shuttle environments and location selection reviews on the one "g" design support mockup are required.

Acceptance tests will be successfully completed on each component (LRU) prior to installation in the vehicle. Details of the component acceptance plan are presented in Paragraph 5.0 of the first section of this document. As an integral part of the vehicle manufacturing build-up, interfaces of ECLS components, lines, etc., will be tested to verify proper installation.

The equipment cooling loop will be leak checked, serviced and checked out as early as practicable in the post installation phase in order that cooling support can be given to the onboard avionic system. The other ECLS subsystems will then be functionally tested using onboard checkout and GSE as applicable. ECLS systems and their interfaces with other subsystems (data management, electrical power, ACPS, displays and controls) will be tested to verify functional and sequential operation and redundancies during a final combined subsystems test.

Horizontal flight mode development and verification tests will be conducted concurrently with other vehicle system test objectives. Temperatures, pressures, and flow rates are measured in key locations to verify the satisfactory operation of the refrigeration packages and adequate cooling, temperature control, and pressurization of the crew compartment, avionics bays, wheel wells, etc. Data is obtained during landing, takeoffs, performance testing, and ferry flights. The subsystem redundancy switching capability is verified. Windshield rain removal and defog capability is verified inflight. The rain removal testing is combined with and utilizes the water spray tanker airplane required for the airbreathing-propulsion anti-icing tests described in Paragraph 5.2.3. A small number of dedicated flight hours has been allotted for rain removal testing and ECLS development/verification testing which requires specific flight conditions.

The verification of the Booster ECLS subsystem in the vertical flight mode is accomplished concurrently with other vehicle system test objectives. Temperatures, pressures and flow rates are measured in key locations to verify the adequacy of air flow, humidity control, temperature control, pressure level and CO_2 level in the crew compartment, avionics bays, wheel wells, equipment bays, etc., during ascent and entry. The final operational verification of satisfactory performance of the system in aerodynamic flight after exposure to entry heat loads and pressure conditions will be obtained during the approach to landing.

Throughout the ECLS development and verification test program, identical GSE is used at the vendors, MDAC, assembly and launch site. This is done to assure that support equipment requirements are fully assessed and that the equipment which is provided is necessary and compatible with the subsystems and procedures which are developed.

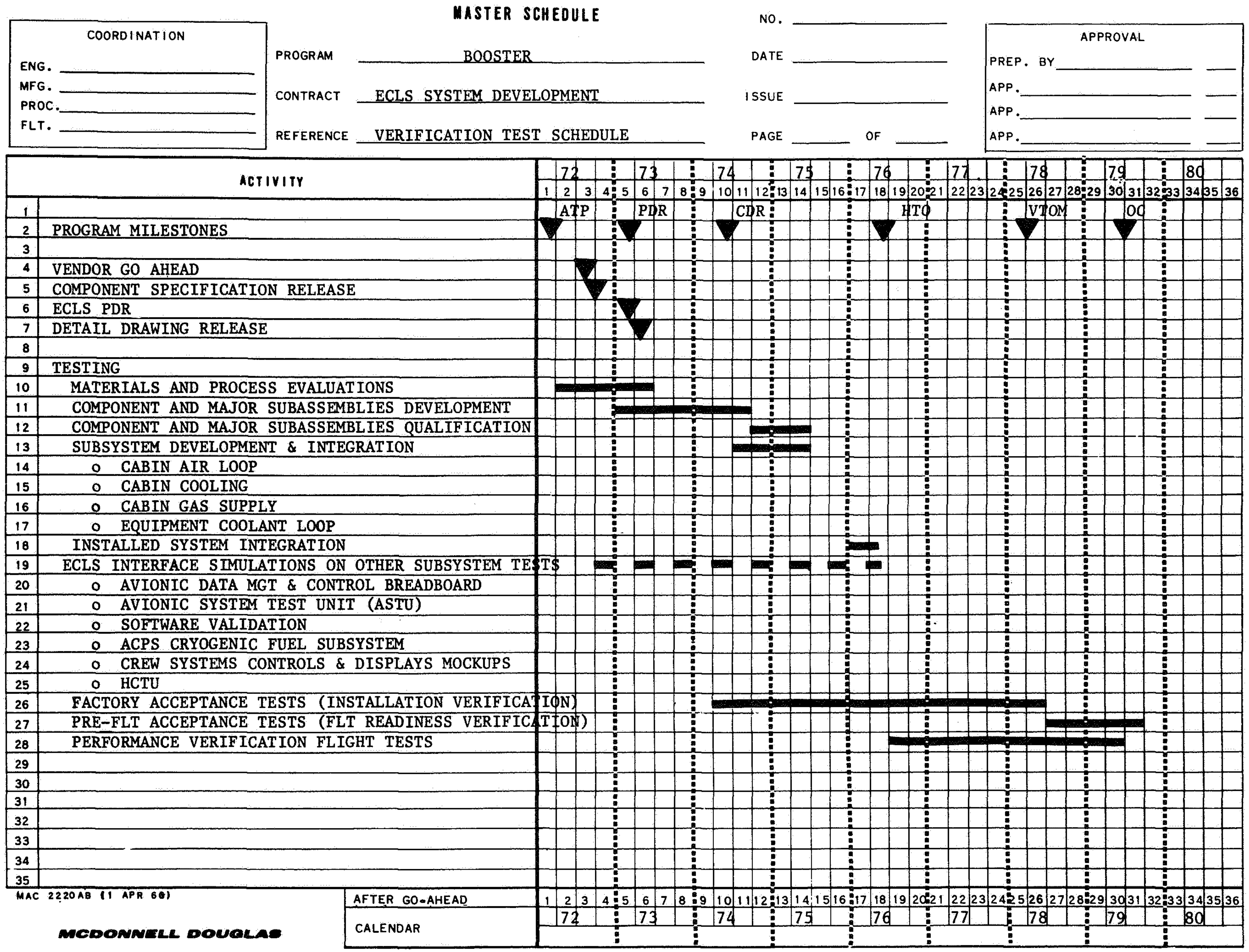
Figure 5.4-5 summarizes the significant information on the development and verification test program. Figure 5.4-6 presents the baseline schedule of these development and verification tests.

BOOSTER ECLS DEVELOPMENT & VERIFICATION TEST SUMMARY

TESTS	REQUIREMENTS AND OBJECTIVES	APPLICABILITY		HARDWARE		FACILITY AND SET-UP
		COMMON	BOOSTER ONLY	QUANTITY	TYPE	
1. MATERIALS AND PROCESS EVALUATIONS	o DESIGN INFORMATION	X		AS APPLICABLE	SPECIMENS & SAMPLES	o METALLURGICAL AND CHEMISTRY LABS, MACHINE AND FABRICATION SHOPS @ MDAC AND THE VENDORS
2. COMPONENT AND MAJOR SUBASSEMBLIES DEVELOPMENT	o DESIGN INFORMATION AND EVALUATIONS	X		1 EACH 1 EACH	SUBASSEMBLY BREAD-BOARD ENGINEERING MODEL	o ENVIRONMENTAL SIMULATION CAPABILITIES, ELECTRICAL POWER, DEMINERALIZED WATER, CRYOGENIC HANDLING FOR N_2, He, & FREON AND DATA SYSTEM @ MDAC'S VENDORS LAB.
3. COMPONENT AND MAJOR SUBASSEMBLIES QUALIFICATION	o VERIFICATION OF SPECIFICATION DESIGN &	X		△1	PRODUCTION PROTOTYPE	o ESSENTIALLY SAME FACILITIES REQMTS AS ABOVE EXCEPT NASA CHAMBER A @ MSC REQ'D FOR FULL SCALE TEST ON SPACE RADIATOR
4. ECLS INTERFACE SIMULATED ON OTHER DEVELOPMENT TESTS o AVIONIC SUBSYSTEM BREADBOARDS o AVIONIC SYSTEM TEST UNIT o CREW SYSTEMS CONTROL & DISPLAY MOCKUPS o HCTU	o VERIFY SUBSYSTEM INTERFACES		X	AS APPLICABLE	ENGINEERING MODELS & SOFTWARE SIMULATIONS AND SAMPLE HARDWARE MOCKUPS	o AS APPLICABLE TO THE TEST ON WHICH THE ECLS INTERFACE IS SIMULATED
5. SUBSYSTEM DEVELOPMENT AND INTEGRATION o CABIN GAS SUPPLY o CABIN COOLANT LOOP o EQUIPMENT COOLANT LOOP o CABIN AIR LOOP	o VERIFICATION OF SUBSYSTEM PERFORMANCE o DEMONSTRATION OF FAILURE TOLERANCE o VERIFICATION OF EMC o VERIFY SUBSYSTEM INTERFACE o DEVELOP PROCEDURES o PROVIDE DATA FOR SOFTWARE DEVELOPMENT o ASSESS GSE NEEDS AND COMPATIBILITY		X	1 SHIP SET EA.	ENGINEERING MODELS AND PRODUCTION PROTOTYPE AS AVAILABLE	o ESSENTIALLY SAME FACILITIES REQMTS AS NOTED FOR 2. ABOVE PLUS SIMPLE HARDWARE AND SOFTWARE SIMULATIONS OF INTERFACING SUBSYSTEMS, PROTOTYPE GSE, AND A COMMERCIAL COMPUTER & TEST SOFTWARE TO FACILITATE CLOSED LOOP TESTING.
6. INSTALLED SYSTEM INTEGRATION	o SYSTEM INTEGRATION VERIFICATION o VERIFICATION OF EMC o VERIFICATION OF PROCEDURES		X	1	PRODUCTION VEHICLE	o 1ST FLIGHT ARTICLE, PRODUCTION GSE & FLIGHT SOFTWARE
7. ACCEPTANCE TEST o COMPONENT o SUBASSEMBLIES o SUBSYSTEM o COMBINED SUBSYSTEM	o CHECK FUNCTIONAL OPERATION o CHECK INTERFACES		X	3	PRODUCTION VEHICLES	o VENDOR FACILITIES o VENDOR MANUFACTURING FACILITIES o PRODUCTION GSE, TEST FLUIDS (GN_2,
8. FLIGHT TESTS o HORIZONTAL TAKEOFF o VERTICAL TAKEOFF	o DEMONSTRATION OF SATISFACTORY INFLIGHT PERFORMANCE		X	3	PRODUCTION VEHICLES	o VERTICAL FLIGHT TEST FACILITY (KSC) o HORIZONTAL FLIGHT TEST FACILITY (EDWARDS AFB & KSC)

1. REFERENCE THE QUALIFICATION TEST PLAN PARAGRAPH 4.0 OF SECTION A

FIGURE 5.4-5


MASTER SCHEDULE
COORDINATION
ENG.
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PROGRAM BOOSTER
CONTRACT ECLS SYSTEM DEVELOPMENT
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ACTIVITY
1
2 PROGRAM MILESTONES
3
4 VENDOR GO AHEAD
5 COMPONENT SPECIFICATION RELEASE
6 ECLS PDR
7 DETAIL DRAWING RELEASE
8
9 TESTING
10 MATERIALS AND PROCESS EVALUATIONS
11 COMPONENT AND MAJOR SUBASSEMBLIES DEVELOPMENT
12 COMPONENT AND MAJOR SUBASSEMBLIES QUALIFICATION
13 SUBSYSTEM DEVELOPMENT & INTEGRATION
14 o CABIN AIR LOOP
15 o CABIN COOLING
16 o CABIN GAS SUPPLY
17 o EQUIPMENT COOLANT LOOP
18 INSTALLED SYSTEM INTEGRATION
19 ECLS INTERFACE SIMULATIONS ON OTHER SUBSYSTEM TESTS
20 o AVIONIC DATA MGT & CONTROL BREADBOARD
21 o AVIONIC SYSTEM TEST UNIT (ASTU)
22 o SOFTWARE VALIDATION
23 o ACPS CRYOGENIC FUEL SUBSYSTEM
24 o CREW SYSTEMS CONTROLS & DISPLAYS MOCKUPS
25 o HCTU
26 FACTORY ACCEPTANCE TESTS (INSTALLATION VERIFICATION)
27 PRE-FLT ACCEPTANCE TESTS (FLT READINESS VERIFICATION)
28 PERFORMANCE VERIFICATION FLIGHT TESTS
29
30
31
32
33
34
35
ATP
PDR
CDR
HTO
VTOM
OC
72 73 74 75 76 77 78 79 80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
AFTER GO-AHEAD
CALENDAR
MAC 2220AB (1 APR 68)
MCDONNELL DOUGLAS

FIGURE 5.4–6

5.4.2 Crew Systems

5.4.2.1 System Description - The Booster crew systems consist of those elements that make up the crew-to-vehicle interface and the escape system for the development flight test program. Conventional and state-of-the-art methods and materials are used in the design and fabrication of the crew systems. There are three major categories of vehicle interface crew systems: (1) crew accommodations, (2) instrument panel controls and displays, and (3) flight control equipment.

The crew accommodations include: Visibility, seats, mobility aids, restraint systems, ingress/egress provisions, and habitability provisions.

Instrument panel controls and displays are grouped on five panels: The main panels, the right and left outboard consoles, the center console and the overhead panel. The arrangement places pilot functions on the left, engineer and navigation functions on the right, and common functions toward the center.

Flight control equipment for pitch and roll is a two-axis side arm stick and for yaw, it is rudder pedals.

A Yankee type escape system is being considered for use in the development flight test program. Additional studies will be conducted to support the final selection.

5.4.2.2 Test Requirements and Justification - The crew system test requirements are delineated in Figure 5.4-7 of this report. They are directed towards verification of the system's ability to meet the performance as specified in the Vehicle CEI Specification.

5.4.2.3 Test Approach and Rationale - Crew accommodation studies and requirement verifications will be accomplished using various full size mockups and simulators (see Figure 5.4-8). Upon completion of the design support and verification test efforts, the mockups and simulators will be available to NASA for training use.

BOOSTER CREW SYSTEMS TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
Demonstrate habitability and functional acceptability of the man to machine interfaces with respect to comfort, subsystem control and displays, lighting, communications, and vision. Included shall be verification of the ability of the crew system to permit onboard and independent recognition and correction of critical system malfunction.	Required prior to flight testing to assure crew safety and performance.
Demonstrate functional acceptability of normal and emergency egress provisions as applicable to each mission phase from prelaunch through landing.	Required prior to flight test to assure crew safety and performance.
Verify the functional acceptability of the emergency crew escape system at their design limit conditions.	Required prior to flight test to assure crew safety and performance.
Check satisfactory component and subsystem assembly, installation, and functional operations after manufacturing.	Required to verify that components and subsystems as manufactured and as installed in the vehicle have been properly assembled and will perform/function within design specifications.
Demonstrate satisfactory inflight subsystem performance during all mission phases.	Required for final verification of subsystem performance.

FIGURE 5.4-7

BOOSTER CREW SYSTEMS DEVELOPMENT AND VERIFICATION SUMMARY

	Crew System									Usage							
	Visibility	Seat	Lighting	Mobility Aids	Restraints	Ingress/Egress	Habitability	Instru. Panel Controls & Displays	Flt. Controls	Product & Installation Verif	Design Aid	Design Eval. & Verif.	Habitability & Functionality	Procedure Dev. & Verif.	Training	Quantity	Description
Simulators Flight	X							X	X		X	X		X	X	1	A high fidelity, full scale, functioning crew station with visual display, modular software to simulate vehicle characteristics and subsystem functions.
Part Task								X			X	X		X	X	◇	High fidelity full scale, functioning mockups of selected part task items such as keyboards, etc.
One "g" Mockup Crew Station & Habitability Area	X	X	X	X		X	X	X	X		X	X	X	X	X	1	High fidelity, full scale wooden & sheet metal mockup with non-functional controls and displays.
Component & LRU Dev. & Qual.	□	□	□	□	□	□	□	□	□			X				◇	Prototype & production hardware
Flight Control Sys. Integ. Tests								X	X			X		X		1	Combined ASTU & HCTU FCS
Acceptance Tests	X	X	X	X	X	X	X	X	X	X						□	Incoming hardware, mfg. installations and pre-flight readiness of flt. vehicles.
Flight Tests	X	X	X	X	X	X	X	X	X			X	X		X	3	Production flight vehicles

◇ As required to support design □ As Applicable

FIGURE 5.4–8

The control and display hardware will undergo normal ground development, and qualification to Shuttle environments unless the hardware is off-the-shelf and/or previously qualified to environments at lease equal to those for the Shuttle. Their compatibility with the crew and procedures will be verified using full scale mockups and simulators.

Compatibility and design of the vehicle flight controls will be established and verified by flight simulations both in the flight simulator and on the ASTU/HCTU flight control system integration tests. Flight conditions will cover all mission phases from preflight checkout and launch through landing and safing of the vehicle. Procedures will also be developed for these tests and they will be verified by usage during the flight test program.

Performance of the escape system will be verified by static firings and by sled tests. Test conditions for these tests will duplicate those design limit conditions which are the most critical for the installation.

Proper installation of the system elements will be verified by factory acceptance tests and vehicle flight readiness will be verified by preflight acceptance tests.

Horizontal and vertical flight tests will verify crew systems concurrently with other vehicle systems tests. The crew station, displays, and controls will be evaluated for habitability and functionality during all mission flight phases. Special emphasis will be given to kinds and quantities of displays and the ability of the crew to use them during ascent, entry and transition. Acceptable operation and the accuracy and legibility of displayed information will be verified.

Figure 5.4-9 presents the schedule for these activities.

Figure 5.4-9

MASTER SCHEDULE

COORDINATION	
ENG.	
MFG.	
PROC.	
FLT.	

PROGRAM: BOOSTER
CONTRACT: CREW SYSTEMS DEVELOPMENT
REFERENCE: & VERIFICATION TEST SCHEDULE

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	ACTIVITY
1	PROGRAM MILESTONES
2	
3	COMPONENT SPECIFICATION RELEASE COMPLETE
4	VENDOR GO AHEAD COMPLETE
5	
6	TESTING
7	COMPONENT & LRU DEVELOPMENT
8	COMPONENT & LRU QUALIFICATION
9	FLIGHT SIMULATOR
10	PART TASK SIMULATORS (AS REQUIRED)
11	ONE "G" HABITABILITY MOCKUP
12	FLIGHT CONTROL SYSTEM PILOT EVALUATION (ASTU/HCTU)
13	ESCAPE SYSTEM APPLICATION VERIFICATION
14	FACTORY ACCEPTANCE TESTS
15	PREFLIGHT ACCEPTANCE TESTS
16	FLIGHT TESTS
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	NOTES: ▽ DELIVER TO NASA FOR TRAINING
27	◇ UPDATE
28	
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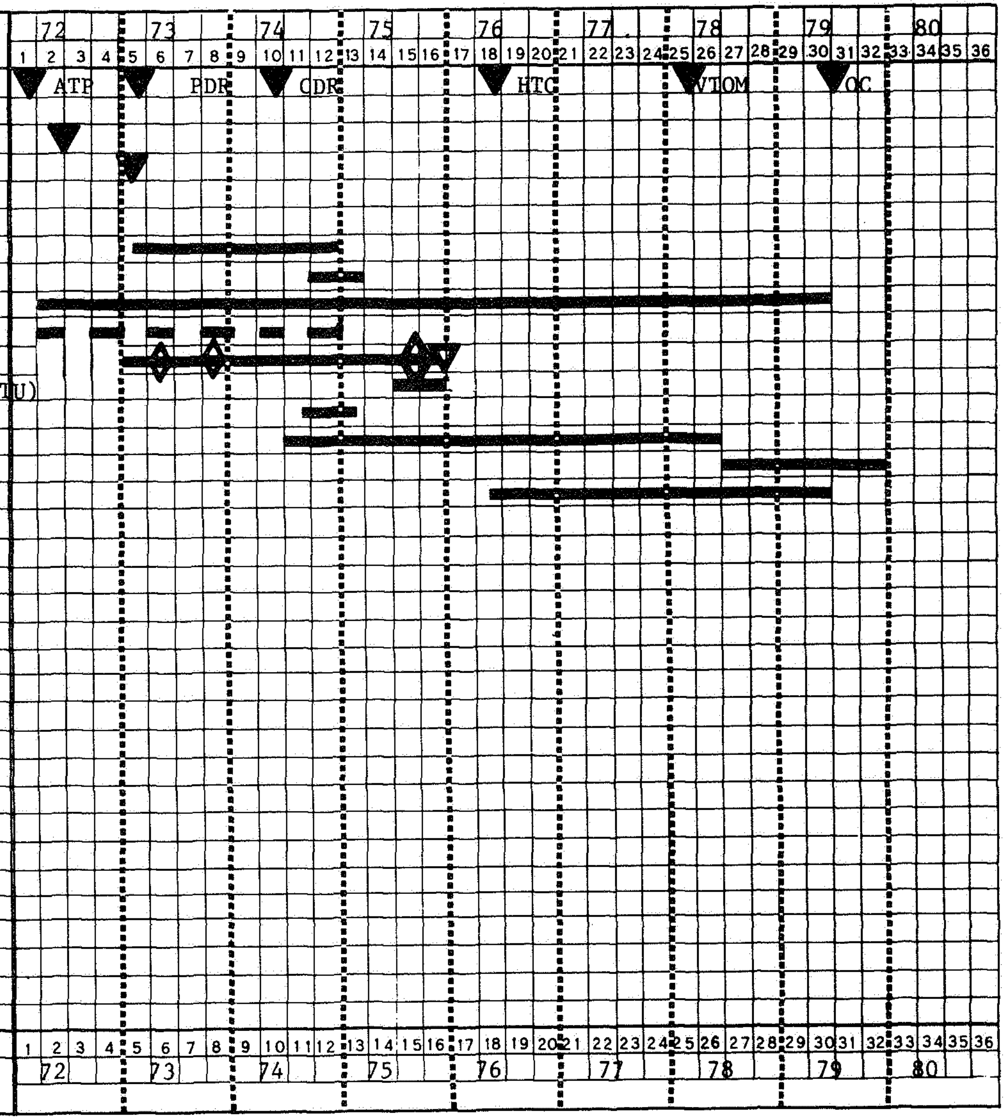

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CALENDAR

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MCDONNELL DOUGLAS

FIGURE 5.4–9

5.5 Power Supply Group

5.5.1 Electrical Power System

5.5.1.1 System Description - The booster electrical power system includes three basic elements: generation, conditioning and distribution. Four systems are provided to meet the required fail operational, fail operational, fail safe capability (Reference Figures 5.5-1 and 5.5-2).

Generation is provided by 120/208 volt, three-phase, 400 cycle alternators rated at 50 KVA continuous power. These alternators are driven by dual mode JP4-H_2/O_2 turbine-drive auxiliary power units (APU). The alternator supplies the AC power required by the main propulsion engines as well as the other vehicle electrical power requirements.

Power distribution to the using line replaceable units (LRU's) is by means of a redundant bus distribution system. Cross-tie capability is provided to parallel distribution busses. Power conditioning is provided by the transformer rectifier units to produce DC power.

5.5.1.2 Test Requirements and Justification - The electrical system test requirements are delineated in Figure 5.5-3. They are directed towards verification of the ability of the system to meet the performance as specified in the vehicle CEI Specification.

5.5.1.3 Test Approach and Rationale - The baseline approach (Figure 5.5-4) is that components, LUR's and minor subassemblies of the system will be subcontracted. The subcontractors will design, develop, and qualify and certify these elements to MDAC specifications using procedures approved by MDAC. Design information and component development tests will be used to porvide data for design analysis and verification of the design approach, and will include testing for materials evaluation and compatibility, tests on fabrication techniques, functional tests on engineering prototypes, and special environmental tests. Test activities will be initiated early in Phase C and continue into Phase D. Qualification by test or assessment

ELECTRICAL POWER SYSTEM
BOOSTER

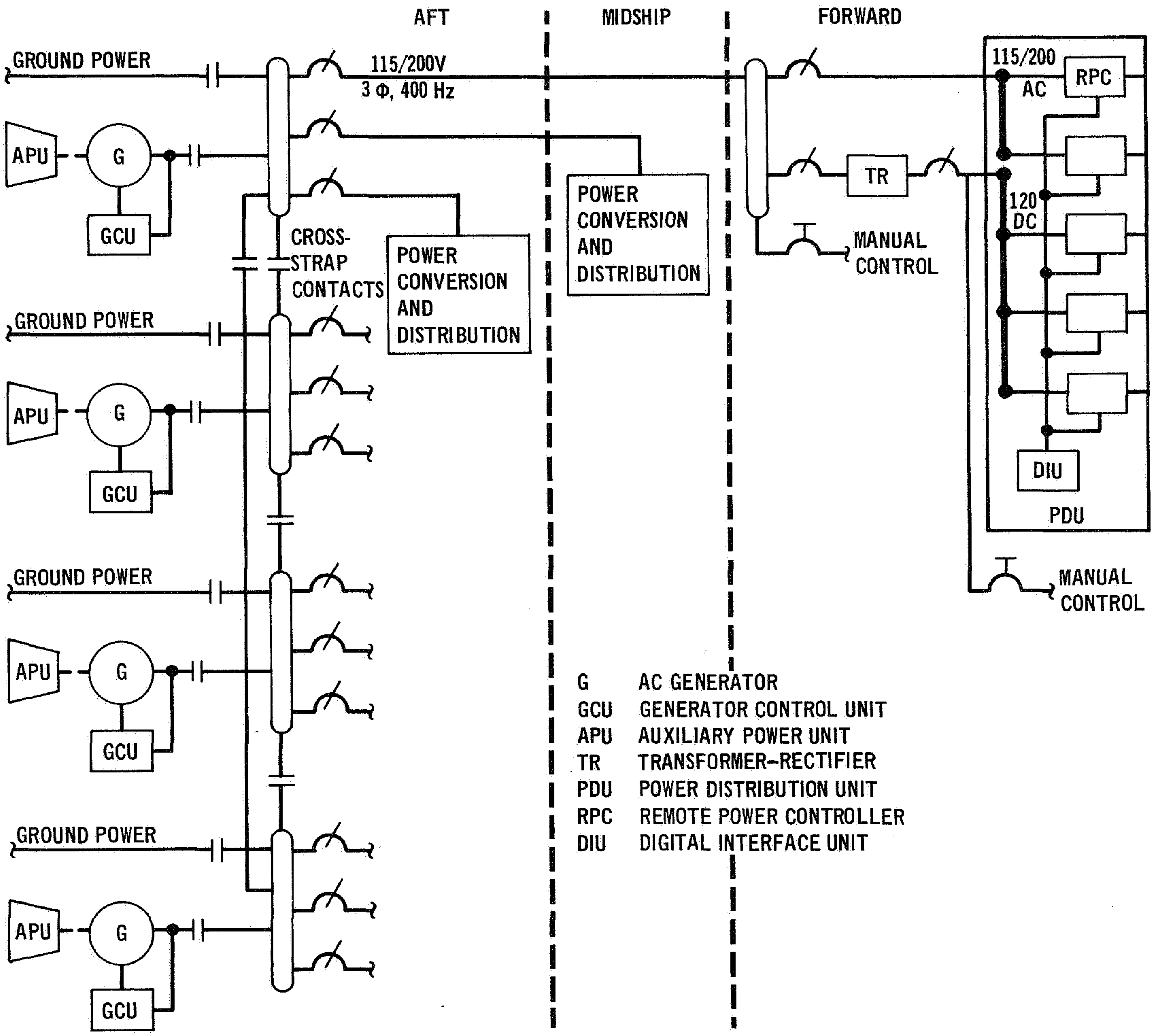


FIGURE 5.5–1

BOOSTER ELECTRICAL POWER SYSTEM INSTALLATION

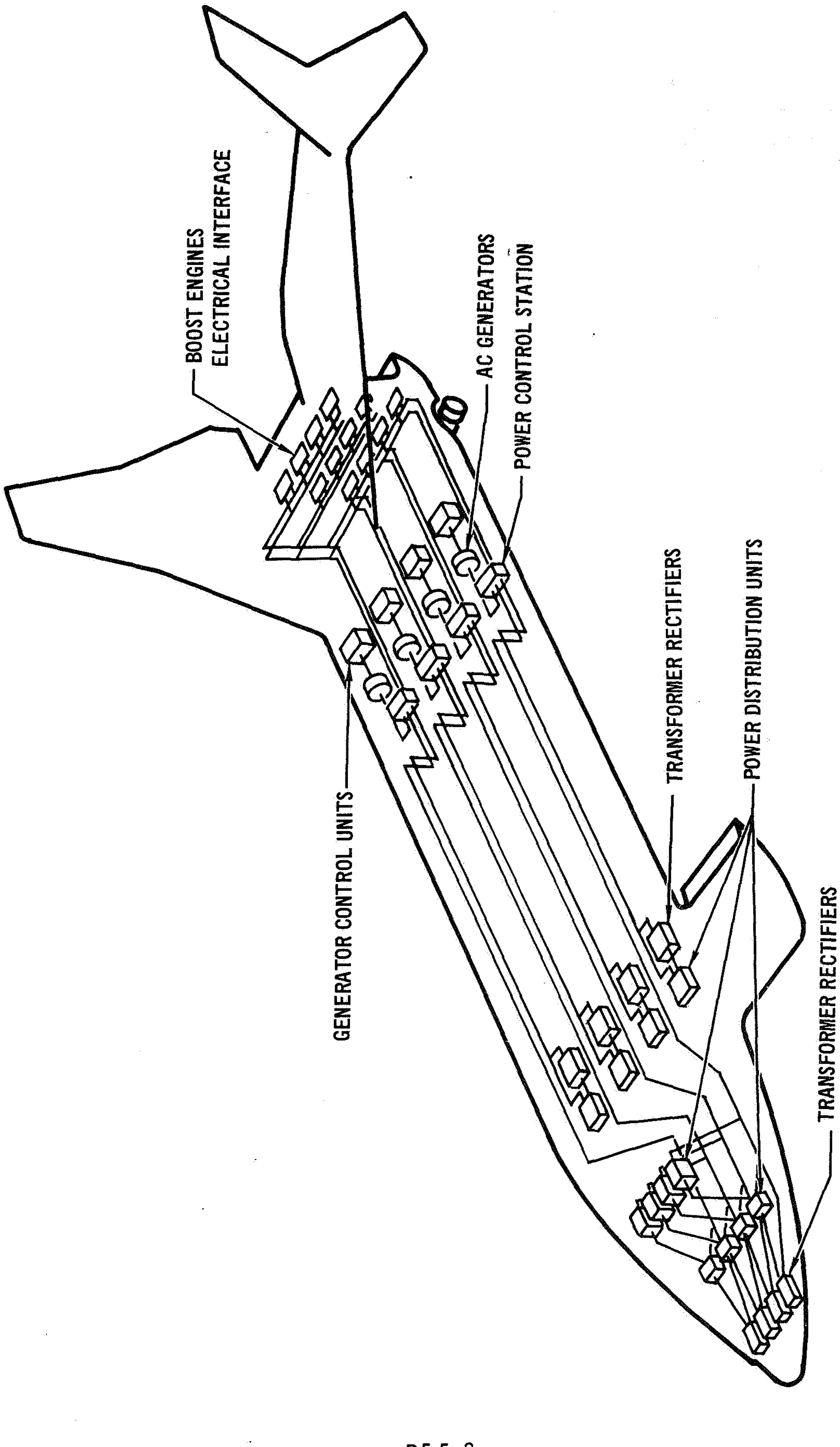


FIGURE 5.5–2

BOOSTER

ELECTRICAL SYSTEM TEST REQUIREMENTS

Test Requirements	Justification
Qualify equipment to environments applicable to specific Space Shuttle usage.	Required to verify environmental compatibility of the item or to support design qualification analysis, and to assure crew safety and mission success.
Verify the functional design and performance of the electrical power system throughout normal and abnormal operating range. Demonstrate subsystem failure tolerance. Verify subsystem EMC. Verify functional compatibility of the electrical power system with the crew and other interfacing vehicle and GSE subsystems.	Required to assure design completeness and performance prior to flight usage. Also minimizes potential risk and associated costs of changes late in the development program; and, enhances crew safety and probability of mission success during the flight test program.
Perform acceptance tests on the installed subsystem components. Acceptance test the electrical power systems interfaces. Verify ability to transfer from external to internal power.	These tests are required to demonstrate proper operation of the installed components of the system and associated mechanical drives, generator output and control.
Demonstrate satisfactory in-flight subsystem performance during all mission phases.	Required for final verification of subsystem performance.

FIGURE 5.5-3

ELECTRICAL SYSTEM DEVELOPMENT & VERIFICATION TEST FLOW

(BOOSTER)

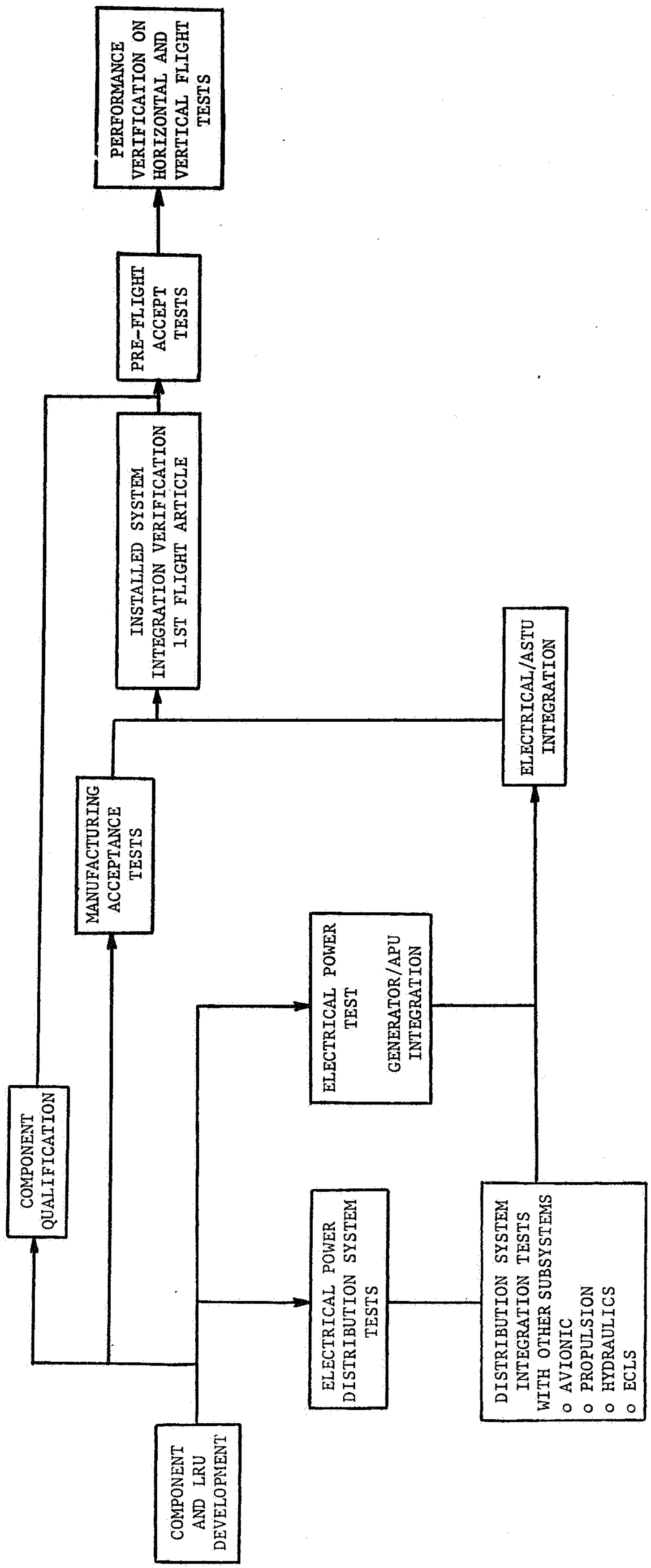


FIGURE 5.5-4

will be conducted on all equipment other than that which has already been qualified to environmenta and performance requirements equal to or greater than those of the Space Shuttle. Additional information on MDAC's approach to qualification is in Paragraph 4. of Section A of this document.

Subsystem development and integration testing will be accomplished as a step-by-step integration of a single, nonredundant set of the electrical system equipment into an electrical power distribution test unit. This unit will include: remote power controllers, power distribution unit, applicable controls and displays, simulated loads and a hardwire simulation of the avionics data management system to facilitate closed loop testing. Testing will include: operation, control, monitor and display evaluation, simulated fault (or malfunction) and recovery, cross-tie switching, and power quality and regulation tests. Information from these power distribution system tests will also resolve any EMI problems.

Other subsystem tests which require electrical power will be supported by laboratory power sources and a simulation of the vehicle electrical distribution system. The electrical interfaces will include actual hardware (connectors, etc.) as practical. The simulated distribution system will be replaced by the electrical power distribution system test unit for electrical/subsystem interface integration tests.

In addition to the distribution system tests, the AC generator will be tested to verify its interfaces. The generator will be tested with the APU and the hydraulic system to determine power generation quality at nominal and off-nominal operating conditions.

Integration of the electrical system and avionics will be accomplished on an Avionics System Test Unit (ASTU). Build-up of this unit will necessarily start with the data management subsystem and the complete electrical power distribution system. Electrical power will be supplied by laboratory sources. As the ASTU build-up continues through the addition of the avionic subsystems, electrical system interfaces will be verified. Test software and computer control will be used to conduct closed-loop simulated missions for all phases from preflight checkout and launch through landing and vehicle safing. Testing at normal and abnormal conditions will verify redundancy management, failure tolerance, power distribution, power transfer, control and display functions, on-board checkout capability, and isolation of failures to the LRU level. During ASTU testing any EMI problems encountered will be resolved.

Integration of the electrical system and the hydraulic system will be accomplished on the Hydraulics and Control Test Unit (HCTU). Electrical power and distribution on the HCTU will be provided by conditioned laboratory power sources and simulated distribution system. Tests on the HCTU will include simulations of all mission phases at normal and abnormal conditions to verify compatibility of the hydraulics and the electrical system interface requirements.

The vehicle installed electrical power and distribution system will be verified for specification conformance on the first flight vehicle concurrent with other subsystem tests. The electrical system tests will verify: power to the main busses, bus tie connections, system controls and displays are functioning properly, and that system operation is compatible with verified flight and checkout software and procedures.

During the manufacturing assembly phase and prior to each booster's horizontal flight, acceptance tests will be performed to validate the electrical power systems.

Prior to the first application of ground power, the electrical power distribution system is verified from each generation source to each load using GSE and test equipment. The Data Management System (DMS) control and monitoring functions are verified. Alternator subsystems are checked out utilizing a means of spinning the APU gear box. The electrical interfaces will be validated using GSE, and functional checks will be performed.

As an integral part of the pre-horizontal flight preparations, the electrical power generation and distribution systems will be checked out with APU's operating both on JP-4 and on hydrogen and oxygen.

The horizontal flight development and verification testing of the booster electrical power subsystem will primarily consist of a functional operational verification, concurrent with other test objectives. Subsystem operation will be monitored throughout the flight test program. The capability of switching redundant items will be verified. A minimum allotment of dedicated horizontal flight time is provided for the attainment of flight development environmental conditions.

The booster electrical power subsystem vertical flight test verification will be done concurrently with other flight objectives. Subsystem operation will be monitored from ascent through entry, and landing. Specific attention will be given to power generation, power distribution, and the ability of the system to meet power demands.

Throughout the electrical system development and verification test program, identical GSE will be used as applicable at the vendors, MDAC, assembly and launch site. This will be done to assure that support equipment requirements are fully accessed and that the GSE is compatible with the subsystems and procedures which are developed.

Figure 5.5-5 summarizes the significant information on the development and verification test program. Listed for each test category are: reference of the applicable test requirement which the test will partially or wholly fulfill, list of test objectives, indication of the tests applicability, the estimated quantity and type of hardware which will be used to meet the test requirements, and a

BOOSTER ELECTRICAL SYSTEM DEVELOPMENT & VERIFICATION TEST SUMMARY

TESTS	REQUIREMENTS AND OBJECTIVES	APPLICABILITY		HARDWARE		FACILITY AND SET-UP
		COMMON	BOOSTER ONLY	QUANTITY	TYPE	
1. MATERIALS & PROCESS EVALUATIONS	o DESIGN INFORMATION	X		AS APPLICABLE	SPECIMEN & SAMPLE	METALLURGICAL AND CHEMISTRY LABS, PRINTED CIRCUIT LAB, MACHINE AND FABRICATION SHOP @ MDAC AND THE VENDORS.
2. COMPONENTS & MAJOR SUBASSEMBLIES DEVELOPMENT	o DESIGN INFORMATION & EVALUATION	X		AS APPLICABLE	BREADBOARD CIRCUIT AND ENGINEERING MODELS	LAB ELECTRICAL POWER, TEST CONSOLE, ELECTRICAL BENCH, AND ENVIRONMENTAL FACILITIES ALL LOCATED AT THE VENDORS AND MDAC.
3. COMPONENT & MAJOR SUBASSEMBLIES QUALIFICATION	o VERIFICATION OF SPECIFICATION DESIGN AND PERFORMANCE	X		△	PRODUCTION	ESSENTIALLY SAME FACILITIES AS ABOVE.
4. ELECTRICAL POWER DISTRIBUTION TEST UNITS o AC CIRCUIT o DC CIRCUIT	o VERIFICATION OF SUBSYSTEM PERFORMANCE o EVALUATE FAILURE TOLERANCE o VERIFICATION OF SUBSYSTEM EMC o VERIFY SUBSYSTEM INTERFACES o DEVELOP PROCEDURES o PROVIDE SOFTWARE DEVELOPMENT DATA o ACCESS GSE NEEDS & COMPATIBILITY		X	1 NONREDUNDANT SHIP SET	ENGINEERING MODELS	LABORATORY POWER SOURCES, SIMULATION OF THE DATA MANAGEMENT & CONTROL SUBSYSTEM & SIMULATED OR ACTUAL VEHICLES LOADS, LOCATED IN MDAC ELECTRICAL LAB.
5. POWER GENERATOR/APU INTEGRATION	o VERIFY INTERFACE COMPATIBILITY o EVALUATE POWER QUALITY		X	1	PRODUCTION	SAME AS REQUIRED FOR APU TESTS PLUS DUMMY LOADS SIMULATION FOR HYDRAULIC & ELECTRICAL OUTPUTS @ MDAC-SACTO.
6. SIMULATIONS OF ELECTRICAL SYSTEM INTERFACES ON OTHER DEVELOPMENT TESTS o AVIONIC SUBSYSTEMS o PROPULSION o HYDRAULICS (HCTU) o ECLS o CREW SYSTEM MOCK-UPS o SOFTWARE VALIDATION	o EVALUATE INTERFACE COMPATIBILITY AND REQUIREMENTS		X	AS APPLICABLE	SIMPLE HARDWARE, SIMULATORS, SOFTWARE PROGRAMS & LABORATORY POWER	AS APPLICABLE TO PRIME TEST SET-UP.
7. ELECTRICAL SYSTEM/ASTU INTEGRATION	o VERIFY SYSTEM PERFORMANCE o VERIFY SYSTEM INTERFACE COMPATIBILITY o DEMONSTRATE FAILURE TOLERANCE AND REDUNDANCY MANAGEMENT o VERIFY ON-BOARD CHECKOUT o VERIFY PROCEDURES o VERIFY EMC		X	1 SHIP SET	PRODUCTION PROTOTYPE	SAME AS REQUIRED FOR ASTU.
8. INSTALLED SYSTEM INTEGRATION	o SYSTEM INTEGRATION VERIFICATION o VERIFICATION OF EMC o VERIFICATION OF PROCEDURES o VERIFICATION OF GSE COMPATIBILITY		X	1	PRODUCTION VEHICLE	VEHICLE, OPERATIONAL GSE, VALIDATED FLT & CHECKOUT SOFTWARE LOCATED @ FINAL ASSY. SITE (BASELINE KSC)
9. ACCEPTANCE TESTS	o CHECK FUNCTIONAL OPERATION & INTERFACES		X	3	PRODUCTION VEHICLES	VENDOR & MFG. FACILITIES, PROD & GSE
10. FLIGHT TEST	o DEMONSTRATION OF INFLIGHT PERFORMANCE		X	3	PRODUCTION VEHICLES	FLIGHT TEST FACILITIES @ KSC (VERTICAL) AND EAFB (HORIZONTAL)

△ REFERENCE THE QUALIFICATION TEST PLAN: PARAGRAPH 4.0 OF SECTION A

FIGURE 5.5-5

summary of the facilities and test setup requirements. Figure 5.5-6 presents the baseline schedule of these development and verification tests.

Figure 5.5-6

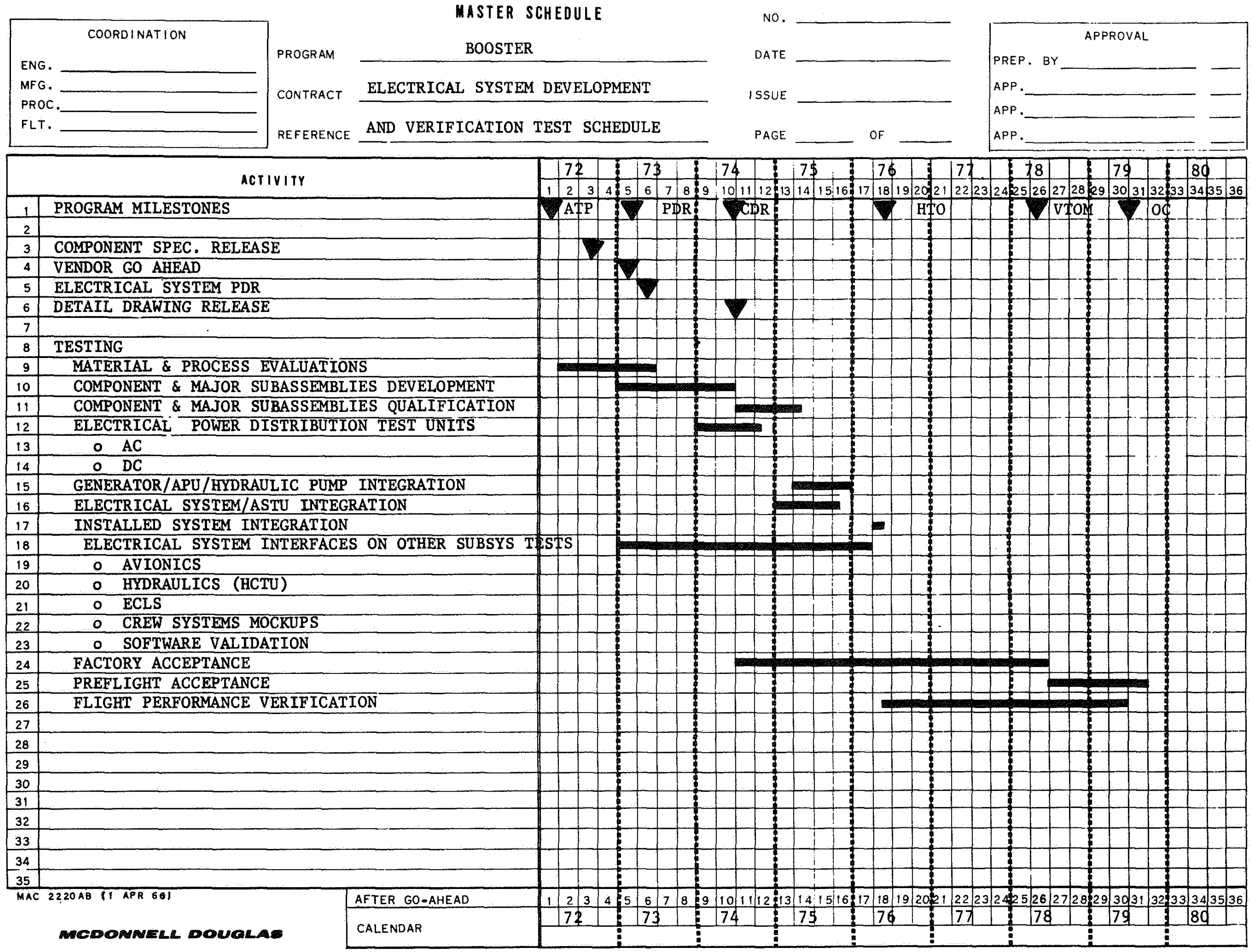


FIGURE 5.5–6

5.5.2 Hydraulic System

5.5.2.1 System Description - The baseline is four completely independent hydraulic systems to provide "fail operational-fail safe" operation of the subsystems: power supply, flight control, landing gear deployment, ABES inlet door opening, anti-skid brakes, nose gear steering, and thrust vector control (TVC).

Conventional type hardware is utilized, operating at a pressure of 3,000 psig. Prime power is supplied by variable displacement in-line pumps driven by H_2/O_2 or JP-4/combustor/turbine drive auxiliary power units (APU's). Distribution is by pressure and return tubing which has both permanent and reconnectable fittings. Flight control actuators are single or tandem, and utilize secondary control elements (one per flight control surface) for interface with the flight control avionics, and logic switching valves at elevon and TVC actuators for fluid direction after system failures. Figure 5.5-7 is a simplified block diagram of the hydraulic system.

5.5.2.2 Test Requirements and Justification - The hydraulic system test requirements are delineated in Figure 5.5-8. They are directed towards verification of the system design's ability to meet the performance as specified in the booster CEI Specification.

5.5.2.3 Test Approach and Rationale - Figure 5.5-9 presents a flow block diagram of the baseline approach to development and verification testing for the Hydraulic system.

Design and information testing will be conducted as required to provide data for design analysis and to verify design approaches. These tests will include material property evaluation, material compatibility tests, evaluations of fabrication techniques, and functional tests on engineering model components. Also as an aid to design, plastic models will be fabricated to evaluate design problem areas.

BOOSTER HYDRAULIC SYSTEM
BLOCK DIAGRAM

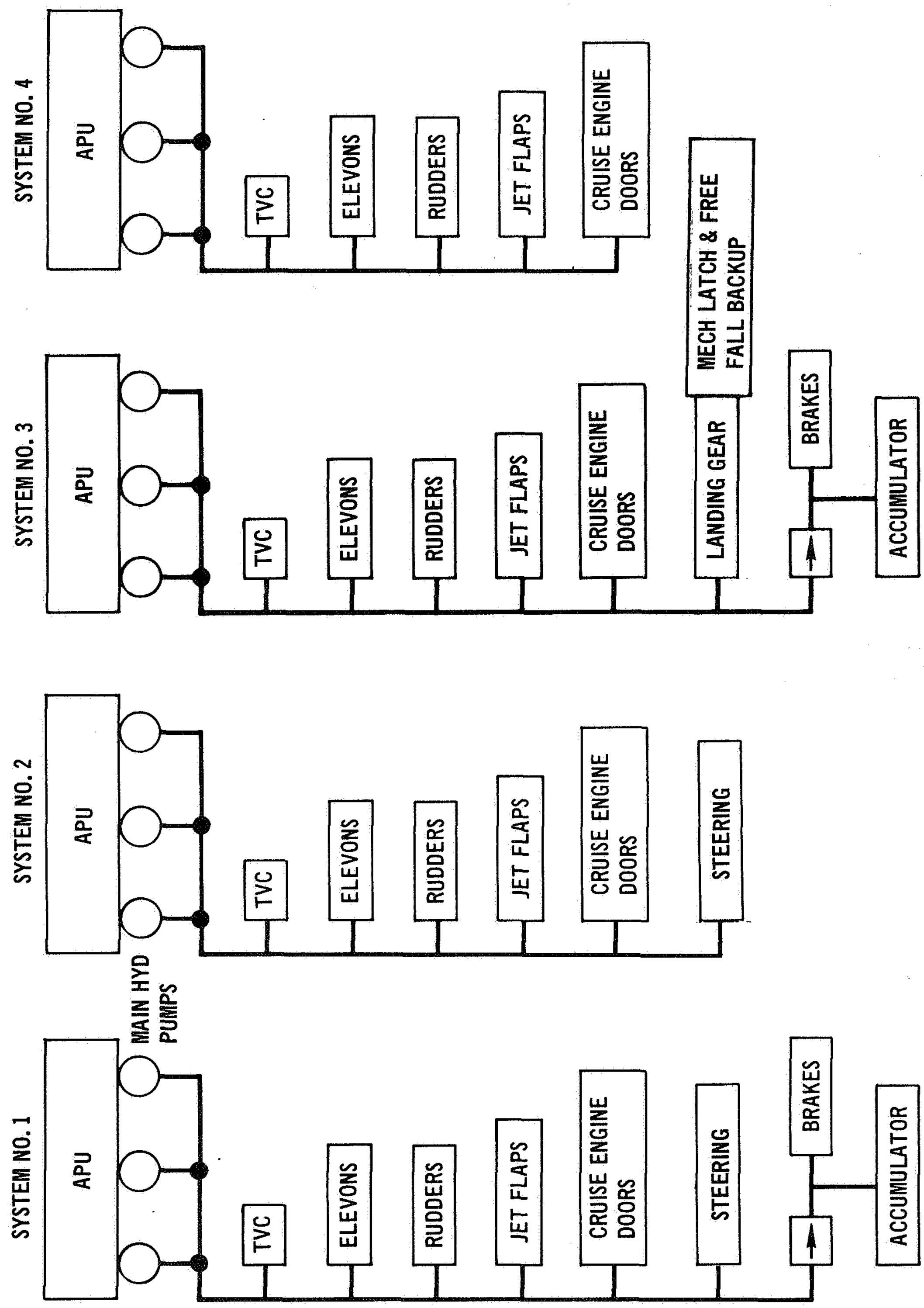


FIGURE 5.5–7

HYDRAULIC SYSTEM TEST REQUIREMENTS

Test Requirements	Justification
Qualify equipment to environment applicable to specific space shuttle usage.	Required to verify environmental compatibility of the item, or to support design qualification analysis, and assure crew safety and mission success. This approach will be more cost-effective than if broad, general environmental requirements were used, thereby causing some items to be over- or under-qualified.
Demonstrate subsystem performance for the spectrum of mission conditions, including operation at nominal and off-nominal conditions.	Required for early development and verification of subsystem design, thereby reducing the potential risks of costly design changes at a later time.
Verify functional compatibility of the hydraulic subsystem with the crew and other (vehicle and GSE) interfacing subsystems .	Required to verify system design compatibility and assure specified performance, and crew safety. This will be required prior to availability of a flight article, to minimize the potential risk of costly design changes later in the program.
Verify crew control capability including override/interrupt capability of the automated flight control functions.	Required to assure design safety and thus enhance crew safety and probability of mission success.
Tests are required after component manufacture, and installation of hydraulic components/systems into the vehicle.	Required to check functional operation, redundancies, leakage integrity and interfaces with other subsystems. This is to verify proper assembly and manufacturing installations.
Demonstrate satisfactory inflight subsystem performance during all mission phases.	Required for final verification of subsystem performance.

FIGURE 5.5–8

HYDRAULIC SYSTEM DEVELOPMENT & VERIFICATION TEST FLOW

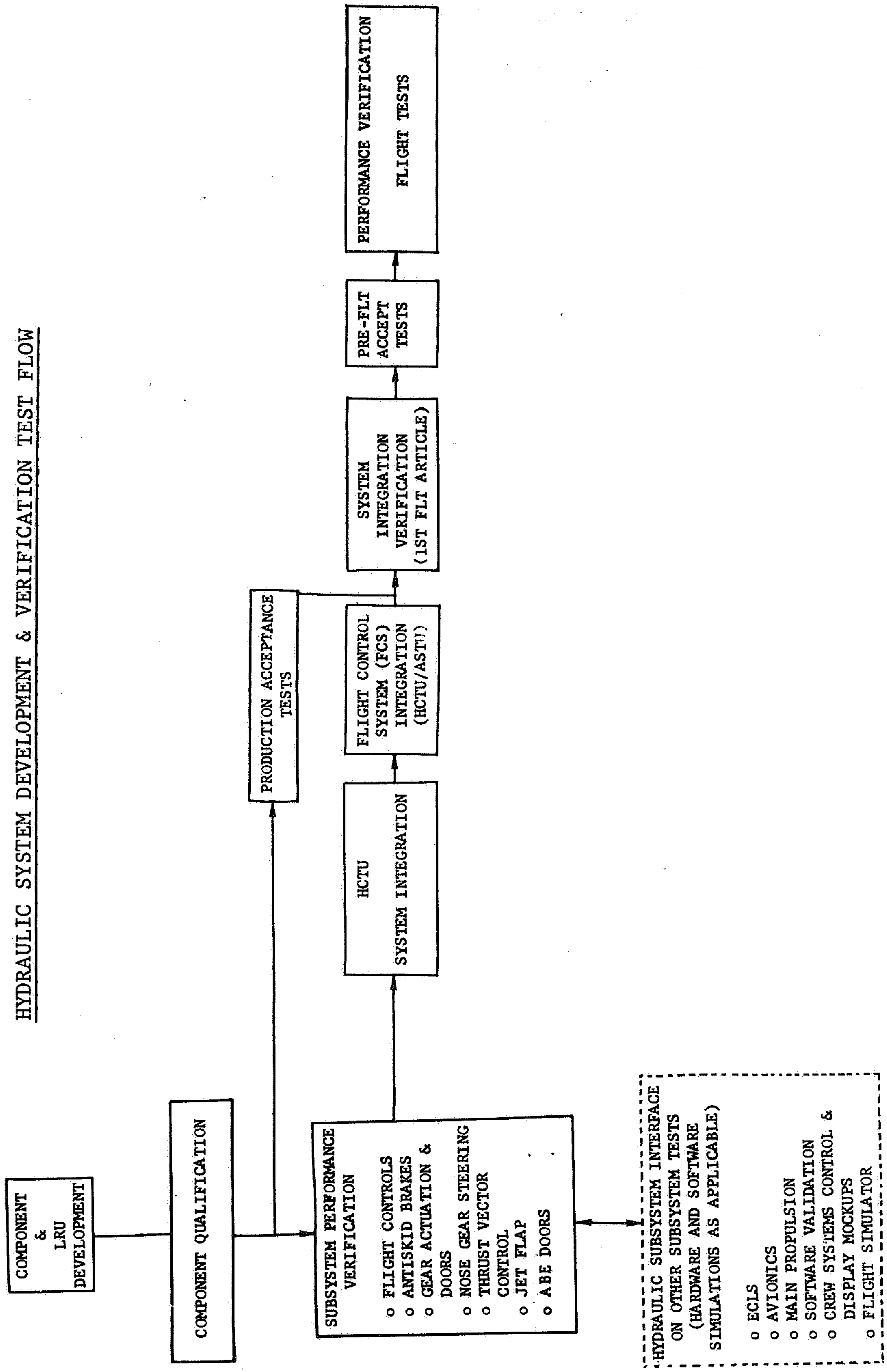


FIGURE 5.5–9

Component qualification tests will be conducted as required to support qualification of production components or subassemblies of the vehicle hydraulic system. Vendors will conduct these tests to MDAC specification using MDAC approved procedures. These tests, design analysis of development tests, and analysis of similar qualified hardware will be used, individually or in combination, to support the contractor's recommendations as to the qualification status of hardware. Details of the MDAC approach to equipment qualification are in Paragraph 4.0 of section A of this document.

Subsystem development and integration testing will be conducted as one step in complete verification of subsystem design and performance. Complete ground test fulfillment of this requirement will not come until integration is verified on the installed subsystems in the first flight article. Some of these subsystem tests will be conducted on a Hydraulic and Controls Test Unit (HCTU) and others will be conducted on small dedicated setups, such as computerized tests of the antiskid brake subsystem on a bench breadboard setup and the landing gear deployment sequencing and functional tests which will be conducted separate from the HCTU. These tests will include functional operations at nominal and off-nominal mission conditions. During these tests, subsystem performance will be evaluated and changes will be made as required to obtain performance that meets the design requirements. Testing will also evaluate the subsystem servicing needs and approaches. Prior to these tests, the subsystem will have been subjected to proof pressure and leak checks.

The HCTU (Figures 5.5-10 and 5.5-11) setup will consist of the entire hydraulic system mounted on a structural framework which simulates vehicle spatial positions. The locations of the components, line lengths, and bends of the plumbing will duplicate the actual installation as nearly as practical. Production actuators will be installed, but the actuated hardware will be simulated

HYDRAULICS & CONTROLS TEST UNIT (HCTU) – BOOSTER
(Concept)

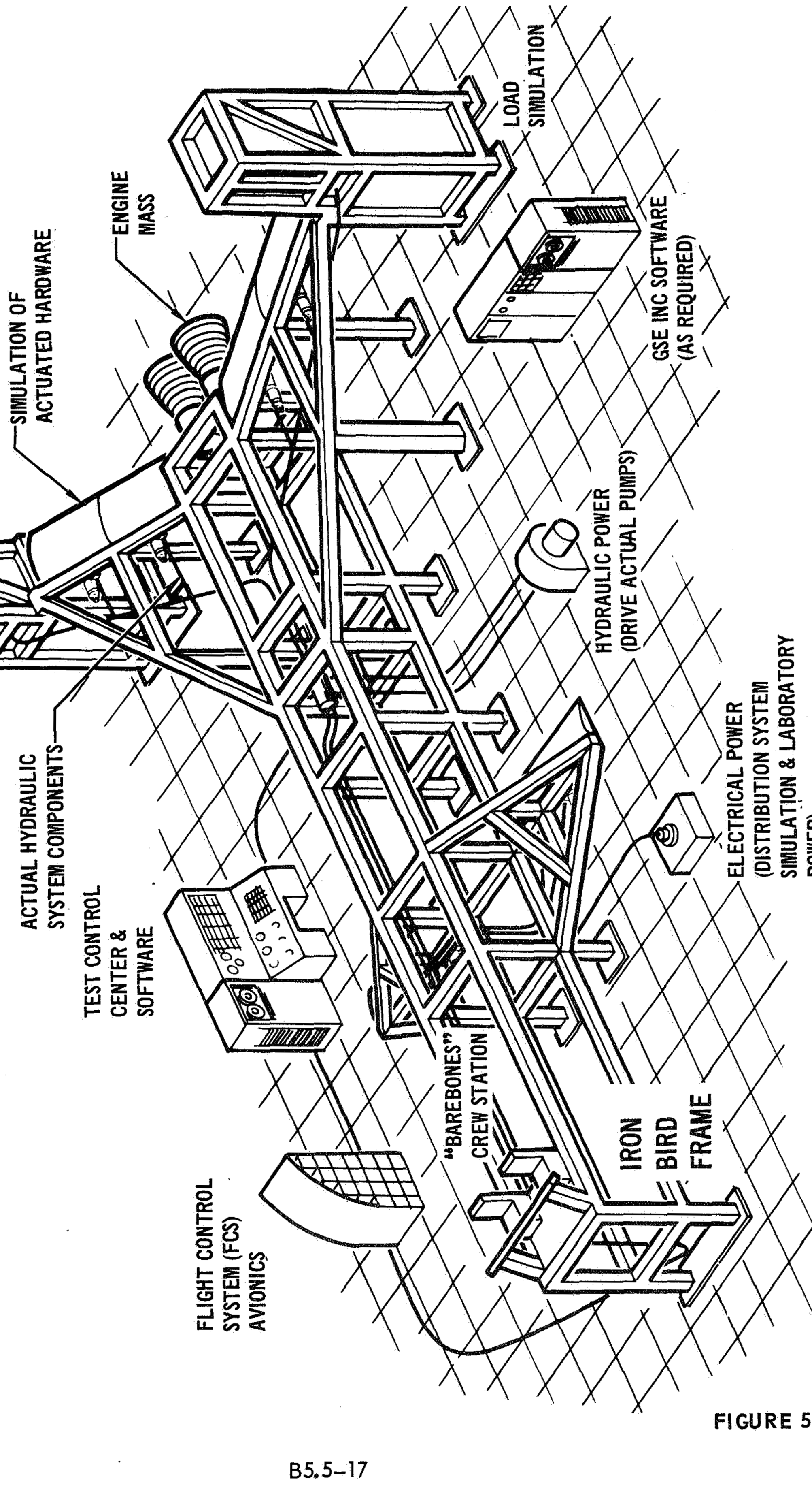


FIGURE 5.5-10

BOOSTER HYDRAULICS AND CONTROLS TEST UNIT (HCTU) DESCRIPTION

EQUIPMENT	SIMULATORS	GSE
1. COMPLETE SHIP SET OF HYDRAULICS EQUIPMENT o LANDING GEAR & DOOR ACTUATION o NOSE GEAR STEERING o JET FLAP ACTUATION o ANTI-SKID BRAKES o FLIGHT CONTROLS o THRUST VECTOR CONTROL 2. REQUIRED FCS & HYDRAULIC CREW STATION CONTROLS & DISPLAYS 3. SET OF HYDRAULIC/ ELECTRIC INTERFACE EQUIPMENT 4. DEVELOPMENT FLIGHT TEST INSTRUMENTATION	1. HARDWARE o GEAR STRUTS & WHEELS o ONE SHIP SET OF CONTROL SURFACES o ELECTRICAL POWER o MINIMUM CREW STATION MOCK UP o LOAD DEVICES FOR CONTROL SURFACES o MASTER TEST CONDUCTOR CONSOLE o APU (DRIVE ACTUAL PUMPS) o DATA BUS o MAIN ENGINES (MASS ONLY) o FLUID COOLING 2. SOFTWARE o DATA MANAGEMENT o LOAD PROGRAMS o FCS PROGRAMS	1. HYDRAULIC SYSTEM CHECK-OUT ADAPTER UNIT 2. HYDRAULIC GROUND UNIT 3. HYDRAULIC SERVICE AND FLUSH UNIT

FIGURE 5.5-11

(e.g., landing gear struts and speed brakes). To facilitate closed loop functional tests on the individual subsystems, the HCTU will have valves to separate and shut off the various subsystems and a commercial computer and test software to provide the avionics data management and control functions. The APU power to the hydraulic pumps and the electrical power supply will be simulated. A crew station with necessary control and display functions will be provided to permit pilot inputs and evaluations.

The HCTU will have means of artificially loading control surfaces and ascent engines to simulate flight loads. The tests on the HCTU will evaluate the entire vehicle hydraulic system for unusual pressure pulsations, back pressures, surges, and temperatures during simulated mission profiles covering prelaunch to landing, and will be used to check the functioning of all hydraulically operated controls and systems. Rated pressure and flow during all phases of critical mission maneuvers will be verified. Maximum flow capabilities of the systems will be demonstrated. Tests will be conducted to evaluate system performance during malfunctions such as loss of one or two hydraulic systems. During these tests, performance requirements such as rates and travels must be met. Excessive interaction between systems, instability, or operational malfunctions will be eliminated by design modifications as necessary.

After the hydraulic system tests on the HCTU, the Avionics flight control system portions of the Avionics Systems Test Unit (ASTU) will be patched in to the HCTU for real time closed-loop or end-to-end testing of the total flight control system. The compatibility of the subsystem interfaces and the mission and checkout software design approach will be verified. Tests will verify operation of the complete flight control system under a cross section of representative and extreme mission conditions. Qualitative and quantitative pilot evaluations of the control system will be performed. The tests will be designed to supplement information gained during the simulator flight controls studies and to obtain pilot acceptance through design iteration of the hardware and software systems. System operation and feel shall also meet with pilot approval.

These FCS integration tests and design limit pressure tests will be completed prior to first flight. All functional cycles of the components on the HCTU will be recorded and used for life cycle history.

Installed hydraulic system integration verification tests will be conducted on the first flight vehicle. These tests will include a repeat of selected integration tests. Also, functional, and leak tests of the hydraulic system will be performed. These and other complete vehicle tests are discussed further in Paragraph 7.2.

Acceptance tests will be successfully completed on each component (LRU) prior to installation in the vehicle. Details of the component acceptance plan are presented in Paragraph 5.0 of the first section of this document.

As an integral part of final manufacturing installation and checkout operations, the hydraulic subsystems will be leak checked and serviced so that the hydraulic systems can provide support for final manufacturing installations/fit checks. Interfaces of the hydraulic systems Data Management System (DMS), electrical power, APU, ECLS, and flight control will be verified, as will functional operation and redundancies.

Final hydraulic systems ground acceptance will occur after a successful pre-horizontal-flight checkout where the APU's, hydraulics, and other subsystems are checked out under normal operating conditions.

Horizontal and vertical flight tests of the hydraulic system will primarily consist of a functional performance verification concurrent with other vehicle system test objectives. System pressures will be measured at key locations during various operational conditions. Steady state and transient operation will be monitored. System response and ability to meet demand will be verified as will accumulator, reservoir and pump operation. Flight data will be compared to pre-launch predictions and test data from the subsystem and system tests on the HCTU and the installed system integration verification tests. A minimum allotment of dedicated flight time will be provided to cover specific flight development conditions.

Throughout the hydraulic system development and verification test program, identical GSE will be used as applicable at the vendors, MDAC, assembly and launch site. This will be done to assure that support equipment requirements are fully assessed and that the equipment which is provided is necessary and compatible with the subsystems and procedures which are developed.

Figure 5.5-12 summarizes the significant information on the development and verification test program. Listed for each test category are: reference of the applicable test requirements which the test will partially or wholly fulfill, list of test objectives, indication of the tests applicability, the estimated quantity and type hardware which will be used to meet the test requirements, and a summary of the facilities and test setup requirements. Figure 5.5-13 presents the baseline schedule of these development and verification tests.

BOOSTER HYDRAULIC DEVELOPMENT AND VERIFICATION TEST SUMMARY

TESTS	REQUIREMENTS AND OBJECTIVES	APPLICABILITY		HARDWARE		FACILITY AND SET-UP
		COMMON	BOOSTER ONLY	QUANTITY	TYPE	
1. MATERIAL AND PROCESS EVALUATIONS	o DESIGN INFORMATION	X		AS APPLICABLE	SPECIMENS & SAMPLES	METALLURGICAL AND CHEMISTRY LABS, MACHINE & FABRICATION SHOP @ MDAC AND THE VENDORS
2. COMPONENT & LRU DEVELOPMENT	o DESIGN INFORMATION & EVALUATION o OBTAIN PERFORMANCE CHARACTERISTICS	X		2 EACH	ENGINEERING MODELS	ENVIRONMENTAL SIMULATION CAPABILITIES, ELECTRICAL POWER, HYDRAULIC BENCHES, DATA SYSTEM, DYNAMIC SHAKERS AS APPLICABLE, @ MDAC VENDORS
3. COMPONENT & LRU QUALIFICATION	o VERIFICATION OF SPECIFICATION DESIGN & PERFORMANCE		X	⚠1	PRODUCTION	ESSENTIALLY SAME FACILITIES AS ABOVE
4. HYDRAULIC PUMP/APU INTEGRATION	o VERIFY PERFORMANCE & COMPATIBILITY	X		1 EACH	PRODUCTION	USE THE APU DEVELOPMENT TEST SETUP AT MDAC SACTO AND ADD INSTRUMENTATION TO EVALUATE HYDRAULIC PUMP PERFORMANCE @ SIMULATED LOADS
5. SUBSYSTEM DEVELOPMENT & INTEGRATION o FLIGHT CONTROLS o LANDING GEAR o BRAKES o NOSE GEAR STEERING o THRUST VECTOR CONTROL o JET FLAP o ABE ENGINE DOORS	o VERIFICATION OF SUBSYSTEM PERFORMANCE o DEMONSTRATE FAILURE TOLERANCE o VERIFY EMC o VERIFY SUBSYSTEM INTERFACES o DEVELOP PROCEDURES o PROVIDE DATA FOR SOFTWARE DEVELOPMENT o ACCESS GSE NEEDS AND COMPATIBILITY o EVALUATE MAINTAINABILITY		X	1 COMPLETE SHIP SET	PRODUCTION	DEDICATED SEPARATE BENCH AND COMPUTER SETUP FOR ANTI-SKID BRAKES AT MDAC VENDOR. A "SHORT JIG" SETUP OF THE LANDING GEAR WITH ASSOCIATED DATA AND HYDRAULIC POWER SUPPLY AND FULL SCALE HCTU AT MDAC HUNTINGTON BEACH
6. INTERFACE OF HYDRAULIC SUBSYSTEMS OTHER SUBSYSTEM DEVELOPMENT TESTS o ELECTRICAL POWER & DISTRIBUTION o ECLS o AVIONICS FCS & DATA MANAGEMENT o MAIN PROPULSION	o INTERFACE COMPATIBILITY DEVELOPMENT		X	AS APPLICABLE	ENGINEERING MODELS SOFTWARE & SIMPLE HARDWARE SIMULATORS AS APPLICABLE	SUBSYSTEM TEST SETUPS AT MDAC LABORATORIES IN HUNTINGTON BEACH EXCEPT FOR MAIN PROPULSION TESTS @ KSC
7. SYSTEM INTEGRATION	SAME AS IN 5. ABOVE BUT AT THE SYSTEM LEVEL		X	1 SHIP SET (FROM 5. ABOVE)	PRODUCTION	HCTU @ MDAC, HUNTINGTON BEACH
8. HYDRAULIC/ELECTRONIC FCS INTEGRATION	SAME AS ABOVE BUT FOR TOTAL END-TO-END INTEGRATED FCS		X	SAME AS ABOVE PLUS ASTU	SAME AS ABOVE	HCTU WITH FCS PORTIONS OF THE ASTU PATCHED IN. THIS TEST SETUP WOULD BE AT MDAC HUNT. BEACH AND WOULD REQUIRE OPERATIONAL GSE & APPLICABLE FLIGHT & CHECKOUT SOFTWARE
9. INSTALLED SYSTEM INTEGRATION VERIFICATION	o VERIFICATION OF SYSTEM COMPATIBILITY WITH TOTAL VEHICLE SYSTEMS o VERIFICATION OF EMC o VERIFICATION OF CHECKOUT AND OPERATING PROCEDURES o VERIFY GSE COMPATIBILITY		X	1	PRODUCTION VEHICLE	FLIGHT ARTICLE LOCATED @ FINAL ASSEMBLY SITE (BASELINE KSC) PRODUCTION GSE, VERIFIED SOFTWARE PROGRAMS
10. ACCEPTANCE TESTS	o CHECK FUNCTIONAL OPERATIONS o CHECK INTERFACES		X	3	PRODUCTION VEHICLES	VENDOR TEST FACILITIES, MDAC MANUFACTURING FACILITIES, PRODUCTION GSE & TEST FLUIDS (GN_2, He, FREON & WATER)
11. DEVELOPMENT AND VERIFICATION FLIGHT TEST	o VERIFY IN-FLIGHT SUBSYSTEM PERFORMANCE		X	3	PRODUCTION VEHICLES	FLIGHT ARTICLES AT HORIZONTAL AND VERTICAL FLIGHT TEST SITES (KSC AND EDWARDS AFB)

⚠1 REFERENCE THE QUALIFICATION TEST PLAN: PARAGRAPH 4.0 OF SECTION A.

FIGURE 5.5-12

FIGURE 5.5-13

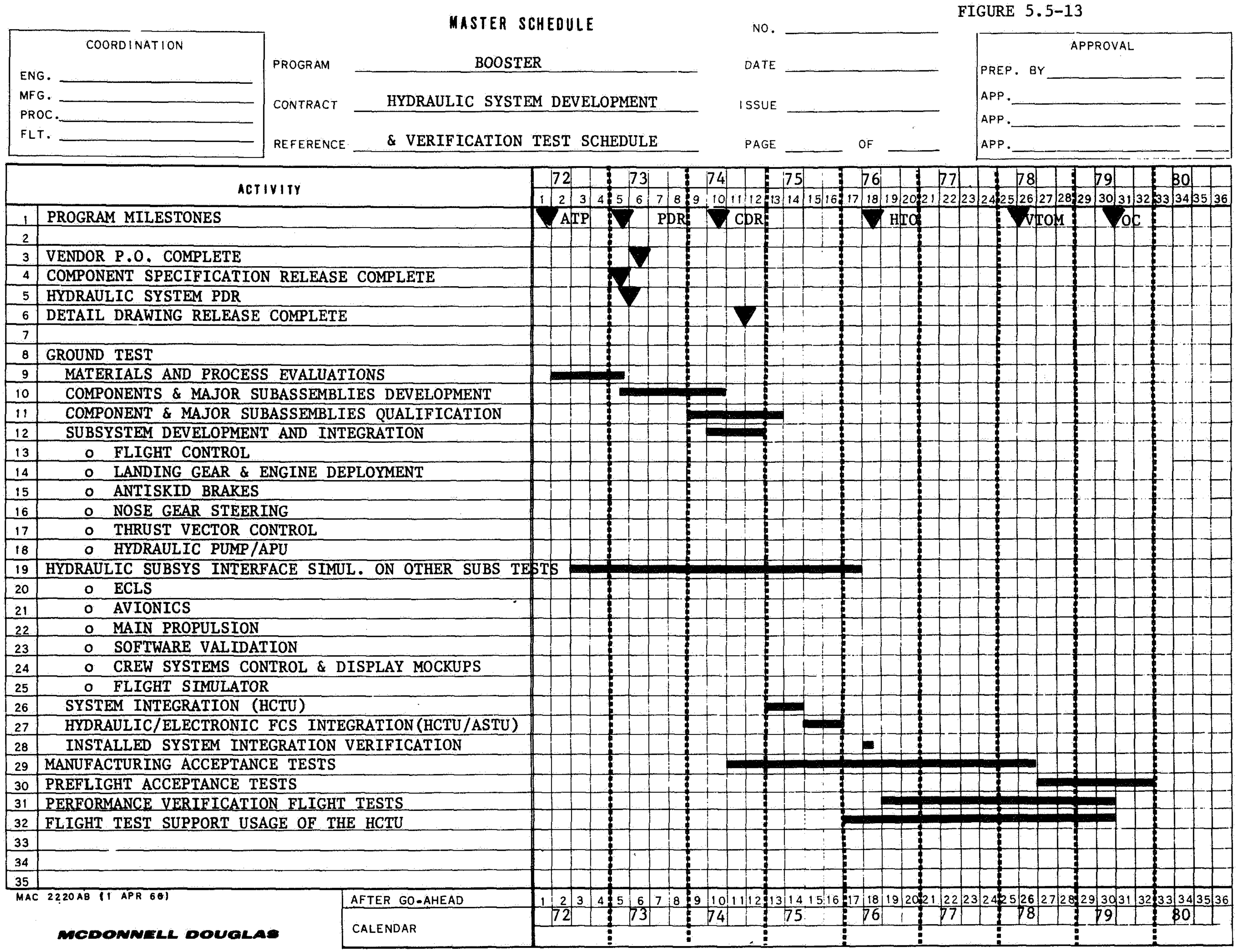


FIGURE 5.5-13

5.6 Ground Support Equipment Tests

5.6.1 Description of GSE and Usage - The GSE required to support ground and flight testing of the Booster will be operational GSE to the maximum extent possible. GSE which cannot be designed accelerated to meet the test schedule will be identified and suitable prototype or special equipment will be used. At conclusion of test usage, the prototype units will be updated to the production or operational configuration.

The major tests that require GSE support are:

- o Hydraulic and Controls Test Unit (HCTU) (Reference Paragraphs 5.5.2 and 6.3)
- o Avionics System Test Unit (ASTU) (Reference Paragraphs 6.1 and 6.2)
- o Main Propulsion System Integration Test Program (Reference Paragraphs 5.2.1 and 6.4)
- o ACPS and APU Integration Tests (Reference Paragraphs 5.2.2 and 5.2.4)
- o Environmental Control and Life Support System Integration Tests (Reference Paragraph 5.4.1)
- o Major structural article verification tests (Reference Paragraph 5.1.7)
- o Vehicle tests (Reference Paragraph 7.0)

A list of GSE and facility support requirements for fluids, power and handling are identified in Report MDC E0388, "Ground Support Equipment".

5.6.2 GSE Test Requirements and Approaches - Test requirements to assist in assuring that the GSE meets the vehicle design interface and performance specification requirements, as well as the facilities design and performance specification requirements, are listed in Figure 5.6-1. It is anticipated that approximately 70% of the new propulsion GSE components will require development testing. It is also anticipated that the logic or arithmetic modules of the Monitor, Display and Control (MDAC) Unit will require development testing along with verification of the ground software.

Verification of GSE will be accomplished by use in support of interfacing tests of vehicle systems. Such testing will be an iterative process and will progressively verify individual functions of the total GSE envelopes. Therefore, final verification would be accompanied by a summation analysis which would show that the ground support equipment verification requirements have been met after full exposure to support of the total interface requirement testing. Whenever GSE availability and equipment requirements for tests are not compatible for support of scheduled development and verification tests, a special demonstration will be arranged, unless these items can be verified by nontest methods.

GSE is categorized into the following groups for test identification.

Simulators - These items provide fit and function simulations to the vehicle under test and supply input and output signals, on demand or sequentially, as required during checkout operations. The simulators will be employed in support of the Avionics System Test Unit (ASTU) tests, the Hydraulics and Control Test Unit (HCTU-"Ironbird") tests, and finally in support of the complete vehicle subsystem integration tests of the first flight vehicle.

Fluid Servicing - Verification of specification requirements of this equipment will be accomplished by successful demonstration of its ability to service fluids. This will be accomplished during the development and verification testing and during checkout and subsystem integration tests of the first flight vehicle.

Handling and Transportation - Equipment used to position, lift, or transport structural subassemblies, equipment items, the assembled vehicle, or the mated assembly will be sequentially demonstrated for specification compliance during handling of major structural test articles and final assembly operations. Main tankage and main engine handling and transportation equipment will also be verified in the main engine cluster static firing tests. The equipment will also be involved in assembly and checkout operations in the Vehicle Assembly Building (VAB), the transporter, and the launch pad.

Propulsion Servicing - Verification of propulsion servicing equipment will be accomplished during the static propulsion system tests. The main propulsion system will be serviced in the vertical position and under conditions similar to actual launch operations. The total demonstration of the servicing equipment will be checked as a two-part function in support of these operations. Final verification will be accomplished at the launch site.

The Airbreathing Propulsion System (ABES) will be finally verified by demonstrations performed during the preflight operations prior to the first horizontal and vertical flight tests.

Electrical/Electronic - The GSE for electronic and electrical vehicle equipment and systems will be verified for specification compliance during checks of the major components and subsystems and the integrated systems. The integrated systems verification of this GSE will be conducted during interface testing involving the HCTU and the ASTU. Final and complete verification will be accomplished during ground acceptance and systems integration testing of the first flight vehicle.

Ground Support Equipment Test Requirements

Test Requirements	Justification
(1) Simulators (Electrical/Mechanical) - Verify that electrical, mechanical, and electronic function generators, and other equipment used to simulate the other vehicle during vehicle system checkout or facility interface checks, are compatible with and deliver/receive stimuli as required by the vehicle system in checkout.	Required to substantiate that the simulators perform fit and functions and provide proper system simulation support during checkout.
(2) Fluids Servicing Equipment - Verify that all GSE required for vehicle liquid and gaseous fluid servicing and checkout meets the requirements set forth in the GSE specification control drawings.	Required to substantiate that the fluids and gaseous GSE meet servicing and checkout requirements.
(3) Handling and Transportation Equipment - Verify that the handling equipment, including prime movers, transporters, erection machinery, installers, slings, access stands, and other miscellaneous handling equipment used to handle and transport the vehicle or its parts, conform to fit/function and strength requirements, and interface with HTO and VTO facilities as applicable.	Required to substantiate that the handling and transportation equipment can be used to handle and move the vehicle or its parts without damage to the vehicle and within personnel safety restrictions.
(4) Propulsion Servicing Equipment - Verify that GSE used in servicing the main propulsion system can deliver cryogenic fuels at the required flow rates and temperatures to the propulsion system. Verify that the required GSE is compatible with the launch facilities and the associated monitor, display, and control unit.	Required to substantiate that this equipment can be used to service (load, unload, and safe) the main propulsion system.

FIGURE 5.6-1

Figure 5.6-1 (Continued)

Test Requirements	Justification
(5) Airbreathing Propulsion System Equipment - Verify that the GSE for servicing the airbreathing engines system can perform servicing operations and that it is compatible with the HTO and launch facilities in monitoring and transferring fuel to and from the vehicle.	Required to substantiate that this servicing equipment can be used to service (fuel/defuel) the ABES.
(6) Electrical/Electronic Equipment - Verify that the electrical and electronic GSE can be used to fault-isolate, checkout, monitor and control systems of the vehicle during checkout and launch operations. Verify that this equipment is compatible with the HTO facilities, the VAB, the maintenance building, and the launch complex.	Required to substantiate that this GSE can be used in appropriate checkout and launch operations.

FIGURE 5.6-1 (Cont.

6. COMBINED SUBSYSTEMS TESTS

These tests provide measurement of the functional characteristics of interfacing subsystems when operating individually or in combination with other operating subsystems. The tests will be performed on the dedicated setups provided for "subsystem tests" (paragraph 5.0) wherever practicable. However, the entire propulsion group, excluding the ABES portion, will be performed with that equipment mounted in the flight vehicle less wings and other unrelated assemblies.

Combined subsystem tests will involve the following activities:

- Avionics/FCS/Software,
- Closed loop Software/Hardware Validation,
- Integrated Hydraulics/Avionics/FCS,
- Propulsion Integration,
- ACPS/APU Integration.

Test data derived from these tests will provide assurance of total interface compatibility prior to being operated in an installed configuration.

6.1 Avionics System Test Unit Program

6.1.2 Test Requirement and Justification - Early verification of avionic subsystems functional EMI compatibility and integration of the avionic subsystems interfaces with other nonavionic subsystems (e.g., electrical, hydraulic, ECLS, etc.) will be required to minimize the risk of costly design changes late in the program.

6.1.3 Test Approach and Rationale - After it has been demonstrated that the subsystems meet their individual design requirements, total avionic system tests will seek assurance of integration of the total avionic system and functional compatibility with other interfacing systems.

An "Avionics Systems Test Unit" (ASTU) will be used for these tests and will be in the MDAC Avionics Laboratory. The ASTU equipment will also be employed in avionic/hydraulic flight control system (FCS) integration and software validation testing. The ASTU will consist of a complete ship set of production type hardware. Installation of the equipment, the cable lengths and interfaces of the actual vehicle will be duplicated within practical limits. Radiated EMC evaluations and nonavionic interface verification will not be accomplished on the ASTU since representative vehicle structure will be minimum and nonavionic system interfaces, with the exception of the electrical distribution system, will be represented with software as simple hardware simulators. Integration of actual interfaces with the other subsystems will be verified on the first flight article.

Test software and a commercial computer will be used to facilitate closed-loop simulated mission testing for all phases from preflight checkout and launch through landing and vehicle safing. These tests will include operation at normal and abnormal operating conditions.

Typical evaluations which will be conducted on these ASTU tests are as follows:

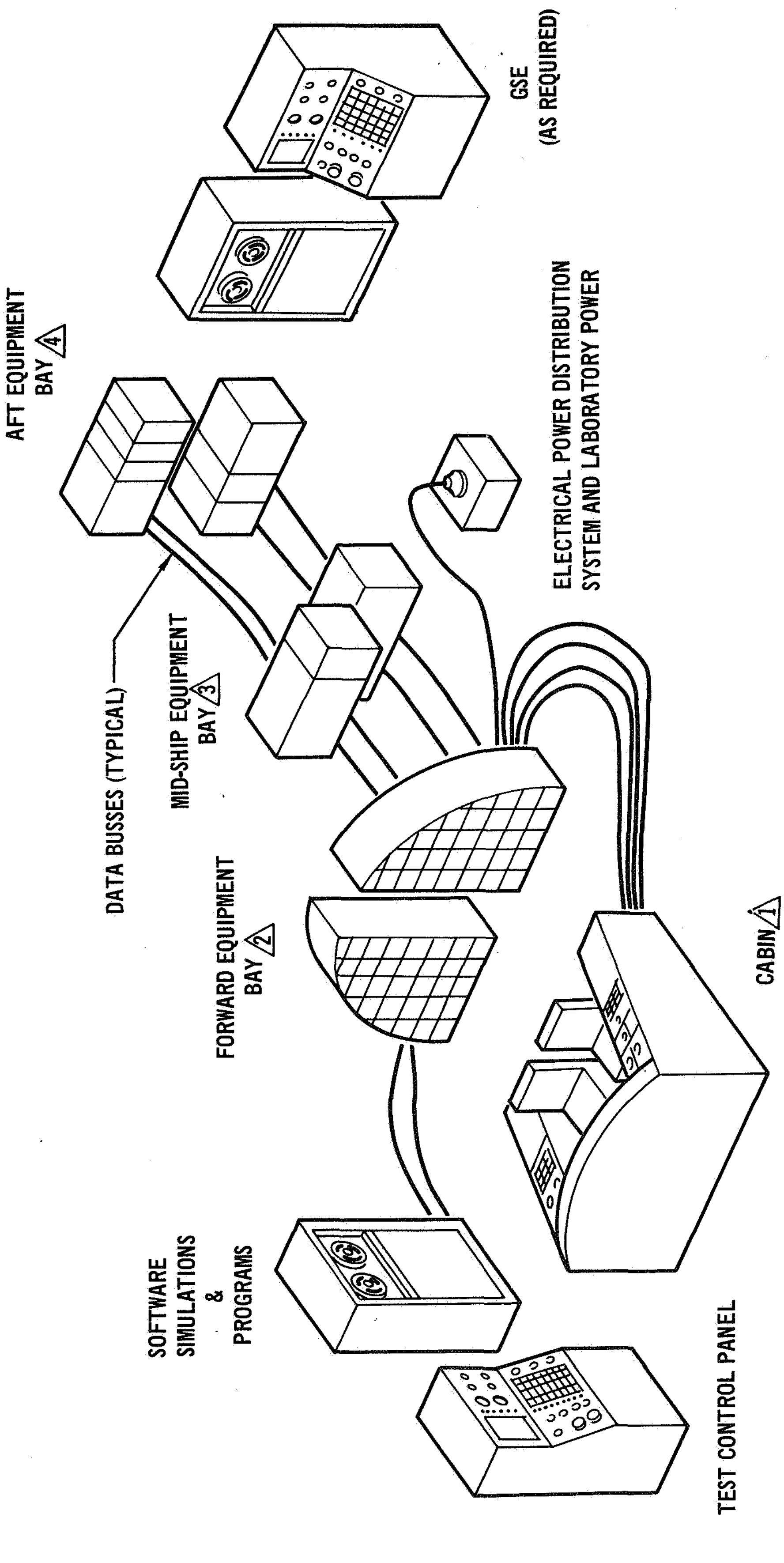
- o Integration of avionic subsystems including redundancy management.
- o Verification of design performance goals.
- o Development and verification of avionic interfaces with other subsystems.
- o Development of operating, checkout, and servicing procedures.

The ASTU setup will remain in existence until all production vehicles of Phase D are flying and its intended integration and software verification usage is completed. It will then be dismantled to reduce continuing engineering support costs. Figures 6.1-1 and 6.1-2 are a pictoral representation of the ASTU and a description summary.

This test facility will be located in the MDAC Avionics Laboratory. This location is baselined because it will assure rapid and comprehensive coordination of tests requirements and results between the design groups and the test laboratory.

For schedule information on the ASTU see Figure 5.3-6 in Paragraph 5.3.1 of this Section.

AVIONICS SYSTEM TEST UNIT (ASTU)
Booster



1. CONTROLS, DISPLAYS, SYSTEM CONTROL UNIT, INTERCOMM & DIUS
2. COMPUTER, MASS MEMORY, IMU, THRUSTER ELECTRONICS, DIUS, NAVAID RADAR ALTIMETER, UHF TRANSCEIVER, & ATC TRANSPONDER.
3. RATE GYROS, FLIGHT CONTROL ELECTRONICS & DIUS
4. FLIGHT CONTROL ELECTRONICS, THRUSTER ELECTRONICS, & DIUS
(NOTE ELECTRICAL POWER DISTRIBUTION UNITS AT EACH LOCATION)

FIGURE 6.1-1

AVIONICS SYSTEMS TEST UNIT (ASTU) DESCRIPTION

EQUIPMENT

1. COMPLETE SHIP SET OF AVIONICS EQUIPMENT (REDUNDANT)
   - o GUIDANCE AND NAVIGATION
   - o DATA MANAGEMENT
   - o FLIGHT CONTROL ELEC ELECTRONICS
   - o COMMUNICATION AND NAVAIDS
   - o DISPLAYS & CONTROLS
   - o SOFTWARE (EXECUTIVE ETC.)
2. COMPLETE SHIP SET OF ELECTRICAL DISTRIBUTION EQUIPMENT
   - o BUSSES
   - o CIRCUIT BREAKERS
   - o FUSES
   - o ETC.
3. DEVELOPMENT FLIGHT TEST INSTRUMENTATION

SIMULATORS

1. HARDWARE
   - o EQUIPMENT BAYS
   - o ELECTRICAL POWER
   - o ELECTRICAL LOADS – LIGHTS, ETC.
   - o ANTENNA LOADS
   - o INSTRUMENT PANEL MOCKUP
   - o MASTER TEST CONTROL PANEL
2. SOFTWARE
   - o HYDRAULIC SYSTEM
   - o ECLS SYSTEM
   - o PROPULSION SYSTEM (MAIN, ACPS & ABE)
   - o FUEL SYSTEM
   - o IMU REFERENCE PROGRAM
   - o COMMUNICATION AND NAVAID INPUT PROGRAMS

GSE

1. ORBITER TO BOOSTER ELECTRICAL SIMULATION
2. BOOSTER INTERFACE SIMULATOR
3. DC POWER SUPPLY
4. AC POWER SUPPLY
5. BUS QUALITY TEST SET
6. GUIDANCE AND NAVIGATION GSE
7. DISPLAY & CONTROL GSE
8. FCS GSE
9. DATA MANAGEMENT GSE
10. COMMUNICATION & NAVAID TEST SETS
11. MONITOR & DISPLAY CONSOLE
12. SOFTWARE
13. SERVICING DIU
14. SYSTEM CONTROL UNIT
15. MISC. CABLING, ETC.
16. NON-AVIONIC SUBSYSTEM GSE THAT INTERFACES WITH AVIONICS

OBJECTIVES

1. INTEGRATION OF AVIONIC SUBSYSTEMS IMCLUDING REDUNDANCY MANAGEMENT
2. VERIFICATION OF DESIGN PERFORMANCE GOALS
3. DEVELOPMENT & VERIFICATION OF AVIONIC INTERFACES WITH OTHER SUBSYSTEMS
4. VERIFICATION OF VEHICLE & GSE SOFTWARE DESIGN APPROACH
5. DEVELOPMENT OF PROCEDURES
   - o OPERATING
   - o CHECKOUT
   - o SERVICING

FIGURE 6.1-2

6.2 Closed Loop Software Validation Test Program

6.2.1 Test Requirement and Justification - Perform a real-time execution of the software program on computer hardware under dynamic closed-loop conditions representative of actual flight to verify its functionality and completeness.

6.2.2 Test Approach and Rationale - Closed-loop validation tests will be performed on flight software programs using the hardware capabilities afforded by the ASTU combined with commercial or GSE computational equipment. The software validation test configuration is shown in Figure 6.2-1 and will provide the most representative execution of the flight program short of actual flight. The commercial computational equipment will be used "to close the loop" and will provide:

(1) vehicle, environmental and end instrument math models, and

(2) the inputs to and accept output commands from the ASTU hardware through the appropriate DIU interfaces to effect closed-loop operation.

A tenative list of the items to be math modeled are shown in Figure 6.2-2. The selection of the actual system hardware to be included in the test configuration will be made to preserve the actual system interfaces where possible and practical in the light that software validation is not meant to be a system performance evaluation. The types of actual hardware to be included are outlined in Figure 6.2-3. Both the horizontal flight and total mission software programs will be formally validated using customer-approved validation test plans. The respective software testing will be completed prior to the avionic system integration verification tests on the first flight articles. A formal period of closed-loop validation testing will not be performed on the ground test program since actual test operation will provide the best proof of software validity.

For schedule information on software validation testing see Figure 5.3-6 of paragraph 5.3.1 of this section.

SOFTWARE VALIDATION TEST CONFIGURATION

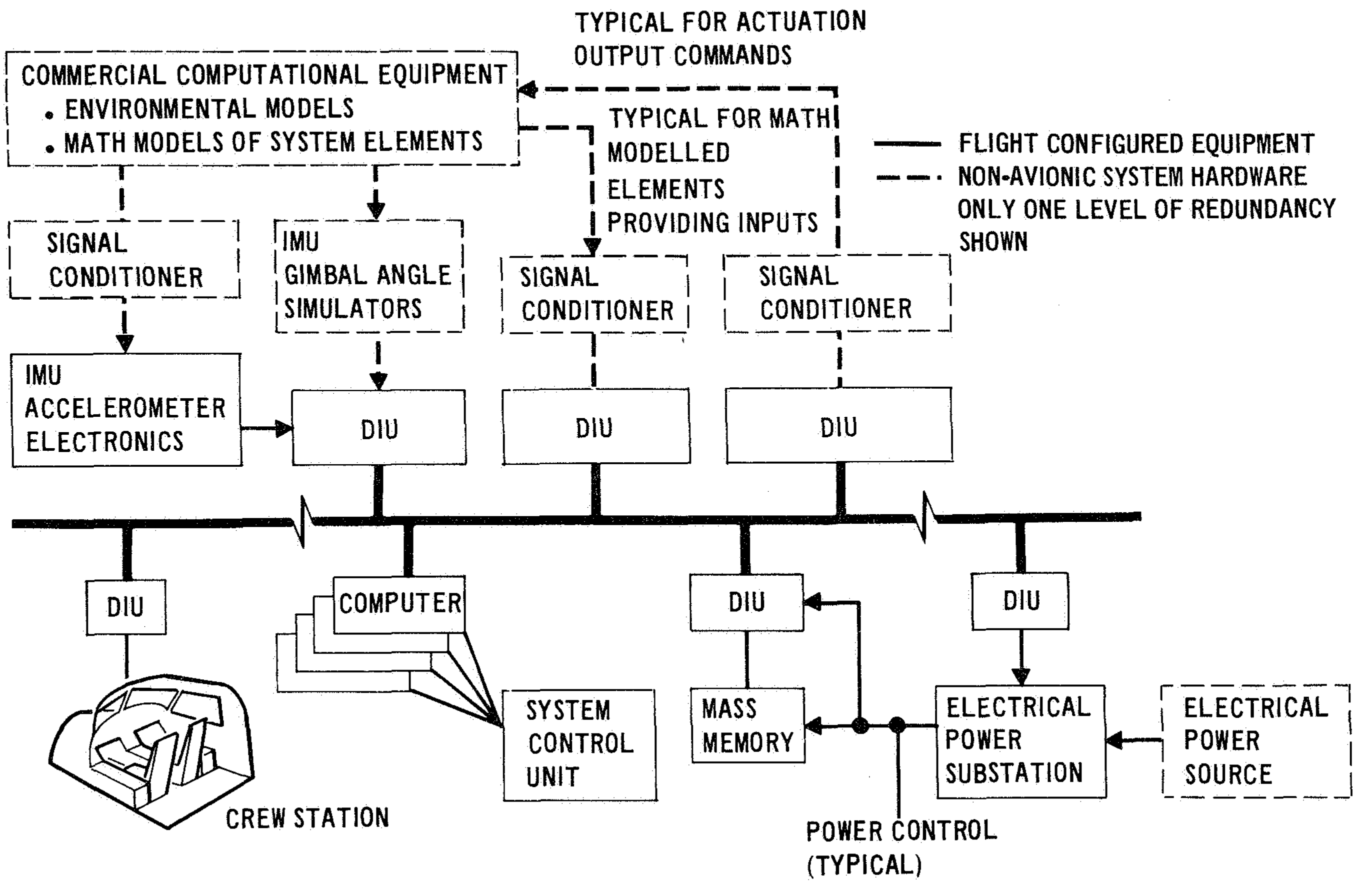


FIGURE 6.2–1

SOFTWARE VALIDATION TESTING

SYSTEM ELEMENTS TO BE MATH MODELLED

- Air Data Sensors
  - Static Pressure
  - Total Pressure
  - Total Temperature
- Propulsion System Elements
  - Operational Model
  - Display Data
- Hydraulic System Elements
  - Closed-Loop Actuator Operational Model
  - Display Data
- Communication Subsystem
- Environmental Control and Life Support Subsystem
  - Operational Model to Provide Display Data
- Landing Aids
  - VOR
  - DME
  - ILS
  - Radar Altimeter
- Star Tracker
- Horizon Sensor
- Rate Gyros
- Accelerometer

FIGURE 6.2-2

SOFTWARE VALIDATION TESTING

FLIGHT CONFIGURED HARDWARE (Four Levels of Redundancy)

HARDWARE ELEMENT	METHOD OF DATA INTERFACE
o Computer, System Control Unit and Data Bus	Actual
o Mass Memory	Actual
o Inertial Platform (Gimbal Angles)	Hardware Simulator of Interface
o Inertial Platform (Accelerometers)	Actual: Suggested Approach is to Electrically Insert Calculated Linear Acceleration Into Accelerometer Rebalance Circuitry to Obtain Corresponding Accelerometer Output Pulses
o Crew Station Controls and Displays (Items That Interface With Data Bus)	Actual
o Electrical Power	o Actual for the Hardware in Simulation; Signal Conditioners for Other Power Sequence and Display Information.

FIGURE 6.2-3

6.3 Integrated Hydraulic/Avionic Flight Control System (FSC) Tests

6.3.1 Test Requirement and Justification - Total flight control system (FCS) integration tests are required early to provide data for vehicle software design, and to verify compatibility of the hydraulic and avionic portions of the system. Early integration tests on this system will minimize the risk of having costly software and/or hardware changes late in the program.

6.3.2 Test Approach and Rationale - Flight control system components and subassembly development tests will have been conducted as will subsystem tests on the Avionic Systems Test Unit (ASTU) and Hydraulics and Controls Test Unit (HCTU). These FCS integration tests will be conducted by combining the applicable portions of the ASTU and the HCTU. Tests will be conducted to verify the subsystem interfaces, and automatic and man-in-the-loop operation of the complete flight control system under a cross section of representative and extreme mission conditions. Both normal and controlled failure mode operation will be simulated for programmed control inputs. Qualitative and quantitative pilot evaluations of the control system will be performed. The tests will be designed to supplement information gained during the simulator flight controls studies and to obtain pilot acceptance through design iteration. During these tests, performance requirements such as rates and travels must be met. Excessive interaction between systems, instability, or operational malfunctions will be eliminated by design modifications as necessary. System operation and feel shall generally meet with pilot approval.

These FCS integration tests will be conducted at MDAC where the ASTU and HCTU will be located. This location is selected to facilitate rapid and comprehensive coordination of test requirements and results between the design groups and the test laboratory. Schedule information on these tests is in Figures 5.3-6 and 5.5-13 of paragraphs 5.3.1 and 5.5.2.

6.4 Propulsion Integration Test Program

The propulsion integration test article provides the capability of performing interrelated tests of all of the propulsion subsystems except the airbreathing engine subsystems. The entire Booster cryogenic systems (ACPS and main engines) and their interrelated GSE and Facility subsystems; the APU subsystem which utilizes propellants from either the ACPS gas storage subsystems or JP fuel from the air-breathing subsystem, and supplies hydraulic power to the main engine actuator and electrical power for the entire Booster; the main engine subsystem; the fuselage structure and TPS (or substitute); the launch purge subsystem which prevents moisture condensation on the cryogenic tanks and must inert and warm certain equipment areas; and all these subsystems control and monitoring avionics from each component to, and including, its appropriate Digital Interface Unit (DIU) make up the integration test article. Each of the subsystems described has an interrelationship with one or more of the related subsystems. The test article will be production hardware which will be returned to the final assembly area where omitted production items will be installed. The Booster will be subjected to a normal post manufacturing checkout ramp and horizontal flight demonstration tests, complete a Flight Readiness Firing and become an operational Booster.

The propulsion tests planned provide a progressive buildup in test complexity in order to obtain a maximum of safety and still provide all necessary Booster integration requirements. Two cryogenic and pneumatic servicing tests and five main engine firing tests have been outlined which will provide sufficient data for subsystem evaluation and subsystem interrelation evaluation between main propulsion, avionics, structure, APU, ACPS, GSE and facility including maintenance and checkout requirements verification. A detailed description of these seven tests is presented in Paragraph 5.2.1.3.2.

Battleship tanks with production components, flight weight tanks on static test stands with production components and combinations of production hardware and battleship tanks were considered for this test program. The article chosen proved the most cost effective and technically the most useful in propulsion system integration testing.

The facility chosen for these tests was the KSC operational launch site.

The operational Launch Umbilical Tower (LUT) will be used for these tests. The GSE and facility connections to the Booster or which supply the Booster's systems will be the same as those utilized for launch. The only exception to this will be a modification to the hold down pins. These attach pins will be modified for added strength for the static tests to provide greater margin of safety when firing all engines with the propellant tanks nearly empty. This will not affect any tested system since these attachments will not be required for a Booster release during these tests.

Existing facilities capable of testing the Booster and new test facilities were considered in addition to the one chosen. The use of the launch facility imposed no new costs. In addition it is technically superior since the chosen test facility does not have to attempt to simulate the expected launch site facility interactions.

The test article will be equipped with a Development Flight Instrumentation (DFI) system during manufacturing. This system is designed to be removed with a minimum scar weight remaining when the Booster becomes operational. The DFI and operational flight instrumentation system will provide the necessary test article data required for the propulsion integration testing.

7. VEHICLE TESTS

This activity comprises all ground tests, calibrations, subsystems checkout, and horizontal flight envelope expansion and performance verification which, by nature, must be performed on the completed vehicle and its installed equipment. The purpose of these tests is substantiate specification requirements for: subsystem functional performance, structural proof, instrumentation calibrations, and quality assurance adequacy. Data from these tests will be pertinent to pre-delivery acceptance by the NASA.

7.1 Vehicle Utilization - The use of complete booster vehicles in the test program will begin in the final assembly and checkout stage of the fabrication process. Testing will continue through horizontal and vertical flight phases and be complete with the fifth or final vertical development flight.

The specific tests to be performed on each subsystem are described more fully in the section of this report dealing with subsystem tests. This section of the report will attempt to describe the sequencing of those tests performed on the flight vehicles. Figure 7.1-1 is presented to aid in this description.

7.1.1 Booster Vehicle Number 1 - The first booster vehicle in final assembly will be the first booster completed and the first one to fly.

Its primary use in the overall Test Plan is the accomplishment of those tests necessary to develop and verify the cruiseback and landing capability of the booster vehicle and will be assigned a majority of the work required in the booster horizontal test program.

In the process of fabricating Booster Number 1, it will be equipped with production systems wherever possible. However, certain subsystems not required for horizontal flight test, or not available for installation, will be deferred until the mid-test vehicle update or the preoperational refurbishment period. These might include such items as the attitude control engines, the airbreathing engines space modifications, and portions of the avionics, thermal protection, and environmental control systems. Simulators will be installed in place of the main propulsion system rocket engines. Provisions, such as brackets, wire bundles, lines and piping, etc., for deferred subsystems will be installed prior to first horizontal flight. Flight test modifications will consist of the Development Flight Instrumentation system (DFI) and a crew escape system. (The DFI is described in Paragraph 7.5.)

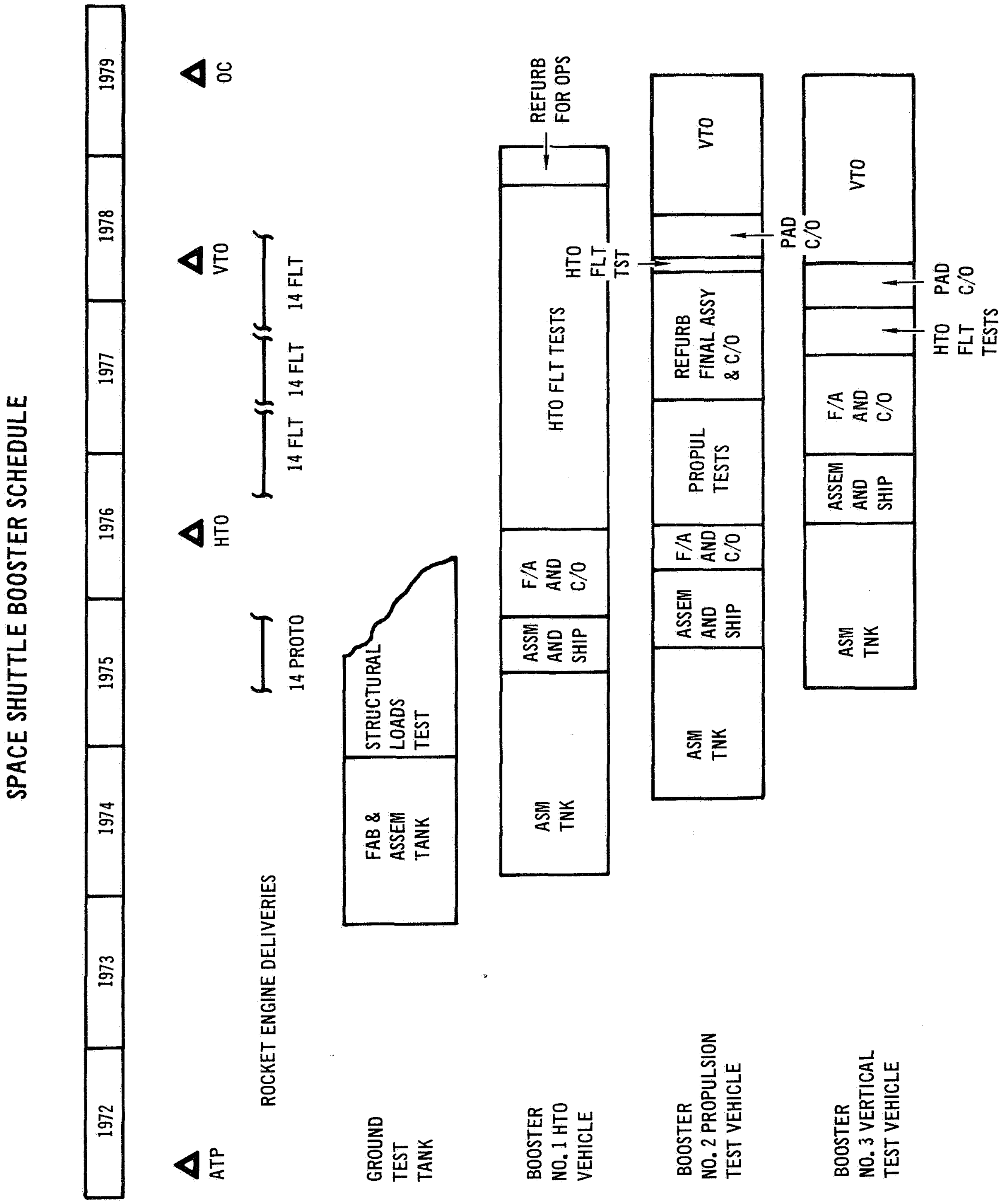

SPACE SHUTTLE BOOSTER SCHEDULE
1972
1973
1974
1975
1976
1977
1978
1979
ATP
HTO
VTO
OC
ROCKET ENGINE DELIVERIES
14 PROTO
14 FLT
14 FLT
14 FLT
GROUND TEST TANK
FAB & ASSEM TANK
STRUCTURAL LOADS TEST
BOOSTER NO. 1 HTO VEHICLE
ASM TNK
ASM AND SHIP
F/A AND C/O
HTO FLT TESTS
REFURB FOR OPS
BOOSTER NO. 2 PROPULSION TEST VEHICLE
ASM TNK
ASSEM AND SHIP
F/A AND C/O
PROPUL TESTS
REFURB FINAL ASSY & C/O
HTO FLT TST
PAD C/O
VTO
BOOSTER NO. 3 VERTICAL TEST VEHICLE
ASM TNK
ASSEM AND SHIP
F/A AND C/O
HTO FLT TESTS
PAD C/O
VTO

FIGURE 7.1–1

During the Final Assembly and Checkout phase of the manufacturing schedule, subsystem tests will be performed on Vehicle 1 as described in the applicable subsystem sections of this report. Loads instrumentation calibrations and airframe dynamic response tests (described in Paragraph 7.2) will also be conducted. In the latter portions of this period, initial engine runs (air breathers) will be performed. Our airplane experience indicates that the engines should be operated in this phase by the flight crew assigned to the first flight in order that they become familiar with the controls, engine response and operation, as well as sounds associated with the vehicle as an aid to early operation.

In the last few weeks before first flight, taxi tests will be conducted. These tests will be rather qualitative in nature being aimed at assuring that control on the ground is smooth and predictable rather than aimed at determining the minimum stopping distance, turning radii, etc. which will be measured later in the horizontal test program. Pre-first-flight taxi tests will be concluded with a high speed taxi run duplicating actual takeoff conditions to the point of lift off.

After first flight, Booster Vehicle Number 1 will undergo several shakedown flights from KSC and then be ferried to Edwards AFB California for further horizontal tests. The selection of Edwards as a test site is addressed in Paragraph 7.4. The horizontal test program is described in Paragraph 7.4 as is the plan for ferrying the vehicle to EAFB.

Upon conclusion of horizontal testing at Edwards AFB, Booster Number 1 will be ferried back to KSC for completion of horizontal tests.

7.1.2 Booster Vehicle No. 2 - Booster Vehicle Number 2 as shown on Figure 7.1-1 will be used in a vastly different manner than Booster Vehicle Number 1 in the Space Shuttle program. Its fabrication will be interrupted in the final assembly process and delivered sans wings, empennage, canards, air breathing engines, and cockpit displays to the launch complex for main propulsion system cluster firing tests. These tests are described fully in Paragraphs 5.2.1 and 6.4.

Subsequent to main propulsion cluster firing tests, Booster Vehicle Number 2 will be returned to the final assembly area for refurbishment and completion of assembly. During this period, the installation of Development Flight Instrumentation (as described in Paragraph 7.5) will be completed.

Following ground checkout tests, it will be operated briefly from KSC in the horizontal mode to "shakedown" its subsystems.

Presently, the timing of this vehicle is such that it is planned to use it in the horizontal mode for final crew training just before the first vertical mated flight (which will be accomplished on Booster Vehicle Number 3).

With the completion of this phase, Booster Vehicle Number 2 will be assigned to the vertical flight test program wherein it will carry out two of the five vertical flights in the development program. (These vertical flight tests are discussed in Paragraph 7.5 of Section A of this report.)

Subsequent to its vertical flight development trials, it will be refurbished for operational use.

7.1.3 Booster Vehicle No. 3 - After undergoing Final Assembly and Checkout, Booster Vehicle Number 3 will be subjected to a brief horizontal flight acceptance test and then be used to conduct horizontal flight tests of booster avionics subsystems. These tests are planned from the operational site at KSC to utilize operational ground facilities such as the Instrument Landing System, and communications facilities.

At the conclusion of these tests Booster Number 3 will be assigned to the "pad checkout" phase of the vertical test program. A detailed schedule of the events and activities in this phase is presented in Section A as Figure 7.1-1. Descriptions of the tests performed on the booster at this time are given in Paragraph 7.2 of this section and in paragraphs 7.2 and 7.4 of Section A.

Subsequently Booster Number 3 is used for three of the five vertical development flights leading to Operational Capability of the Space Shuttle System, after which it is refurbished for operational use.

7.2 Ground Verification Tests - In addition to normal manufacturing cycle quality assurance and functional acceptance tests, the following verification tests will be performed using a flight vehicle as the test article. These tests are designed to meet the requirements presented in Figure 7.2-1.

INTEGRATED BOOSTER VEHICLE TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
(1) Flight test structural instrumentation shall be calibrated.	Required to provide accurate flight loads substantiation.
(2) Low-level dynamic response tests shall be performed on the first booster airframe, in the horizontal position, prior to first flight.	Required in order to substantiate vehicle dynamics mathematical model.
(3) Radiated and conducted electromagnetic compatibility of installed subsystems shall be verified on the first complete flight vehicle (prior to flight) during test and checkout operations on the installed systems.	Required in order to substantiate design analysis and assure flight safety. The EMC tests on ground test units will not complete resolution of potential EMI problems due to radiation, since the setup will not provide the complete vehicle representation of shielding and cable routing.
(4) The functional compatibility of installed systems or subsystems shall be verified by demonstration tests.	Required in order to demonstrate capabilities of system to function in harmony and without jeopardizing flight safety.
(5) The booster vehicle to be employed in the initial vertical take-off flight shall be subjected to a minimum duration flight readiness firing of the main propulsion system.	To assure the launch readiness of this vehicle which will not previously have been employed in any cryogenic fluid operation. This will provide level of confidence in attaining the start sequence without any other deleterious effect on this particular vehicle.

FIGURE 7.2-1

(a) Structural Loads Application - The assembled airframes to be employed in flight tests will be subjected to structural loading conditions to calibrate flight test instrumentation. The test will be scheduled to occur prior to installation of those TPS assemblies that would obviate desired access to basic structural locations needed as load input points. The airframe will be installed in a test fixturing system which will provide loads applications and reactions which simulate conditions established as necessary for instrumentation calibration. The test systems will be designed to expedite testing by rapid conversion from one test condition to another. Loads will be applied and reacted in a manner to prevent local damage to the vehicle as a result of loads introduction and test system interlocks will be included to provide a fail-safe test system. Instrumentation of the airframe will fulfill flight test requirements and will be correlated with major structural section-level test data.

Facilities requirements are a structural loading capability with data acquisition and reduction system at the final assembly site. Test operations will be the responsibility of MDAC.

The test schedule is shown in Figure 7.1-1 and is coordinated with the airframe assembly tests to be completed prior to flight. Testing must be completed successfully prior to release of the airframe for flight.

(b) Airframe Dynamic Response Test - A nondestructive Ground Vibration Test (GVT) will be performed on the first fully assembled flight vehicle prior to horizontal take-off flight testing. The vehicle will have all major mass systems installed or simulated, onboard systems will be installed and operating as required, and the vehicle will be as nearly as possible in a "flight ready" configuration. The airframe will be tested in a horizontal attitude while being supported by low-spring-rate devices. Electro-mechanical exciters will be used for low level dynamic force inputs to the structure. Structural response will be determined from force, velocity, or acceleration data (or combinations of these) acquired during test. Mode shape and frequency response data will be obtained. It is anticipated that the Air Force portable multiple shaker ground vibration test system (designed for the XB-70A) will be used to perform this test.

The vehicle support area of the final assembly building will be used to conduct this testing. The Air Force owned vehicle support devices, dynamic exciter systems, and a dynamics data acquisition and reduction system will be required as test equipment. Test operations will be the responsibility of MDAC.

The test schedule is shown in Figure 7.1-1 and is coordinated within the airframe assembly verification test program.

This testing is essential to substantiate the structural dynamics analytical model(s) of the vehicle for verification of airframe flutter characteristics prior to flight.

(c) <u>Installed Subsystem Integration</u> - In addition to normal manufacturing cycle quality assurance and functional acceptance tests on the subsystems, the following ground tests will be performed using the first flight article.

The installed electrical power and distribution system will be verified for specification conformance on the first flight vehicle concurrent with other system tests. The electrical system tests will verify: (1) power to the main buses, (2) bus tie connections, (3) system controls and displays are functioning properly, and (4) that system operation is compatible with verified flight and checkout software and procedures.

Installed avionics system integration verification tests will also be conducted using the first assembled flight vehicle prior to first horizontal take-off flight. Similar tests will be performed later using the first vertical flight vehicle since the first HTO vehicle may not have total mission capability at that time. The two major areas of concern will be evaluation of electromagnetic compatibility (EMC), and assurance of avionics and software integration with the other vehicle systems.

Although EMC testing will have been conducted at the component, subsystem, and system level, the nature of those test setups will not have lent themselves to complete or comprehensive evaluation of radiated electromagnetic compatibility. Tests on the complete vehicle will include effects of structure conductivity and shielding, and actual cable routing.

Both vehicle and GSE will be evaluated under representative mission conditions from prelaunch through landing. Throughout the testing, interfaces with the other subsystems will be evaluated and test results will be compared to those from the ASTU to determine if there are any problem areas. Results of these tests may be used to improve the ASTU and software validation setups. Any flight-initial interface problems will be resolved before first flight.

Installed hydraulic system testing will be accomplished after the ground acceptance proof pressure and leak tests. All hydraulic subsystems will be functionally tested. The vehicle will be placed on jacks for tests involving landing gear extension and retraction. Both vehicle power and GSE power sources will be used. Pump failure will be simulated and the affected subsystems operated. Operations will also be conducted with off-nominal reservoir fluid levels to simulate the effects of volume changes due to thermal expansion and contraction. Subsystem functioning will be observed at the various operating conditions. Functional checks will also be conducted while the airbreathing engines are running to determine if there is any undesirable vibration of plumbing or equipment. Data from these tests will be compared to the results from the Hydraulics and Controls Test Unit.

Installed ECLS system tests will include EMC tests, system response tests, functional tests of the air distribution system to verify adequate delivery to all parts of the system, sound level measurement in the habitable vehicle areas, evaluation of nominal and off-nominal system operation with normal and programmed interface failures, evaluation of heat transfer efficiency, installed duct proof pressure tests, and tests to evaluate complete system servicing needs, adequacy of procedures, and GSE.

Acoustic evaluations will also include the effects of all other installed systems during operation. Objectionable noise levels, if there are any, will be minimized within the limits of safe functional performance of the subsystems.

Installed airbreathing engines systems ground testing prior to first horizontal flight will include fuel quantity gauging calibration, full thrust run-ups, engine acceleration calibration from idle to full power and vehicle horizontal roll acceleration tests. These tests will provide adequate confidence to initiate the horizontal flight test program.

(d) Flight Readiness Firing (FRF) - The first booster assembled with production main engines will be the first booster launched vertically. This vehicle will be static fired (with the orbiter mated) to vehicle its flight readiness prior to mated flight. The booster will be mounted on an operational Launch Umbilical Tower. This test facility will be the same as that utilized for booster propulsion integration testing described in Paragraph 6.4. The vehicle will be loaded with fluids in a manner identical to that planned for a launch countdown. A component functional check will be made of all components which can be safely functioned after propellant loading. The vehicle will then complete a final launch-sequenced preparation including starting of APU's and transferring to internal power. The main engine start sequencing will be identical to a proposed launch countdown condition. The main engines will be allowed to operate only long enough to allow the main propulsion system start transients to stabilize, and then will be shut down. Each of the ACPS engines will be operated after main engine shutdown to verify operation.

7.3 Ground Acceptance Testing - Ground acceptance testing of the vehicle includes those acceptance tests performed on components prior to installation in the vehicle, manufacturing-in-process tests, subsystem, and combined subsystems tests performed upon completion of vehicle assembly. The equipment (component) acceptance plan, delineated in Paragraph 5 of Section A, will be integrated with the ground acceptance test plan as defined in this section. Figure 7.3-1 presents a representative flow plan of vehicle acceptance from component tests to final acceptance prior to horizontal flight.

7.3.1 Requirements - Requirements for acceptance test of the vehicle from initial manufacturing assembly to final pre-horizontal flight acceptance testing are presented in Figure 7.3-2. Requirements for component acceptance are presented in Paragraph 5 of Section A. Acceptance test requirements for each subsystem are included under the appropriate subsection of Paragraph 5.

Approach - The acceptance test program will verify that each vehicle and all its subsystems have been correctly assembled and will develop confidence in each vehicle's flight readiness for initial horizontal flight. The program is based on a building block philosophy, from in-depth testing of components prior to installation at the factory to final checkout immediately prior to takeoff. Testing will be nonrepetitive in nature (e.g. testing to the same depth will not be repeated in successive test sequences). Development and acceptance test functions will be combined in an integrated approach to the testing of development vehicles which subsequently become operational.

Interwoven with the manufacturing buildup of the vehicle, tests are performed to validate subassemblies prior to their installation, subsystem interfaces to these subassemblies, subsystems end-to-end, and subsystems in combination. The contractor's overall approach to vehicle acceptance test follows. Subsystem

REPRESENTATIVE BOOSTER FACTORY ACCEPTANCE

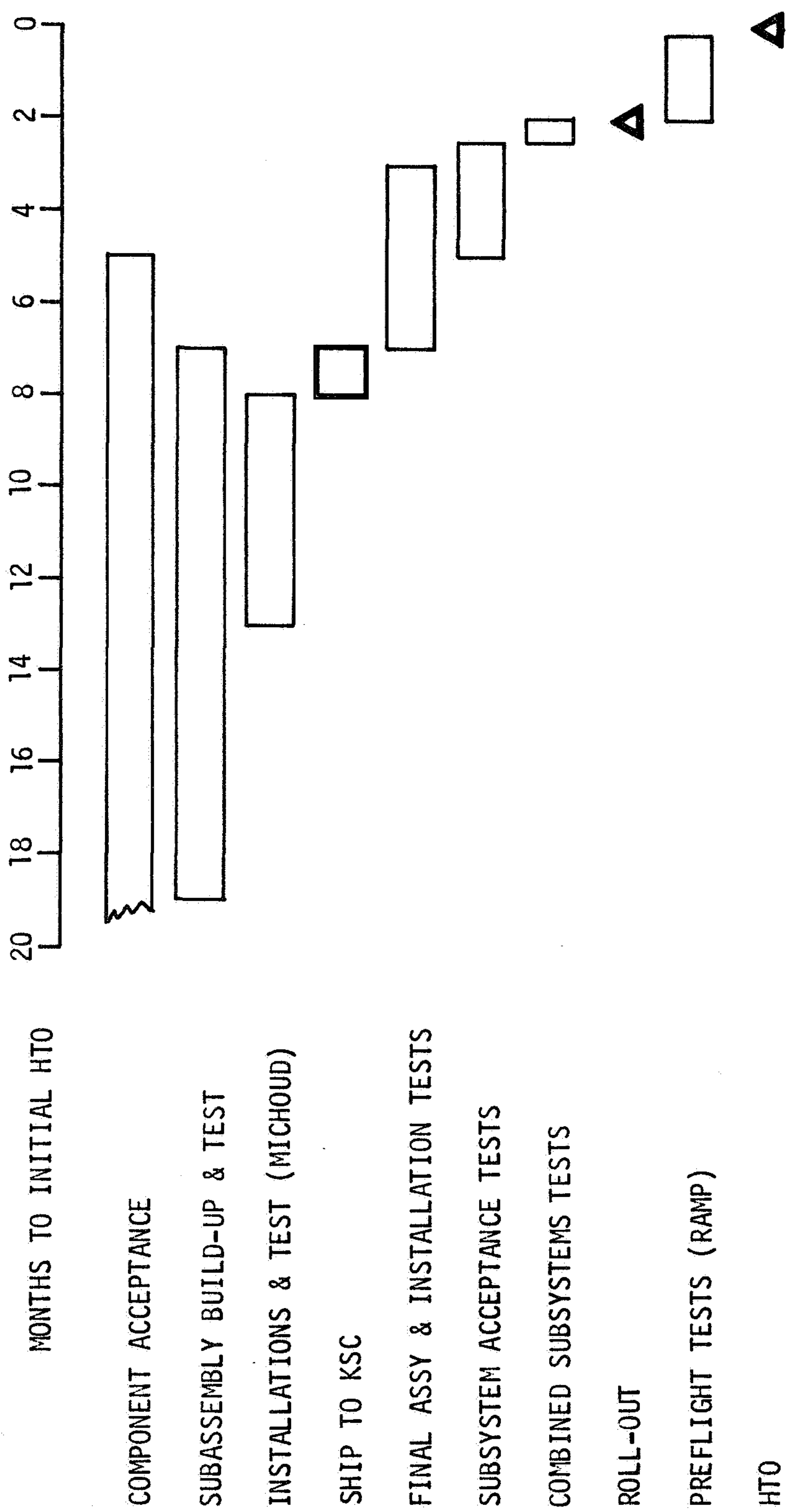


FIGURE 7.3–1

GROUND FACTORY ACCEPTANCE TEST REQUIREMENTS

Test Requirements	Justification
Subassembly Acceptance Tests - Acceptance tests shall be performed on subassemblies such as modules, cabling, fluid lines, and tanks prior to their installation in next assemblies, and shall include continuity and insulation tests, breakdown and grounding tests, proof pressure and leakage tests, or functional tests, as appropriate.	To verify that the subassemblies perform within design specifications, and to accomplish this as early in the manufacturing cycle as practical so that any discrepancies can be corrected without impacting the overall schedule.
Installation Acceptance Tests - Tests shall be performed during the manufacturing phase to verify proper installations.	To verify that components and subassemblies are properly installed and to validate their interfaces.
Subsystem Acceptance Tests - These shall be performed on subsystems mounted in the vehicle.	Tests are required to checkout each subsystem after the manufacturing installations are complete.
Combined Subsystems Acceptance Tests - After each subsystem has been tested and validated individually, the combined subsystems are operated and checked out simultaneously.	To check that both interfacing and noninterfacing subsystems function properly during simultaneous operations.
Preflight Tests - Prior to horizontal flight, a series of ground tests are required that check out all subsystems that will be called upon to operate during the horizontal acceptance flights. These include tests on the airbreathing engines, the APU's, integrated avionics, the flight controls, flight test instrumentation, etc., and includes taxi tests.	To check that all subsystems required for takeoff, horizontal flight and landing are functional prior to committing the vehicle to flight.

FIGURE 7.3-2

approaches are included under the appropriate subsection of Paragraph 5 of this section.

Component Acceptance - Prior to installation, functional tests will be performed on procured components and modules to the depth necessary to verify acceptable characteristics. Details of the contractor's approach to component acceptance are found in Paragraph 5 of Section A.

Subassembly Acceptance - Tests will be performed on subassemblies during the manufacturing phase to verify proper assembly and that integrity, operation and performance are within design specifications. Examples of subassemblies and of how they are tested are as follows:

(a) Cabling - Continuity, insulation breakdown, shielding and grounding tests will be performed.

(b) Fluid Lines, Manifolds, Tanks - Fabricated assemblies will be hydrostatically or pneumostatically proof pressure tested and leak tested. Jacketed cryogenic lines will be cold shocked using a cryogenic fluid and leak tested using a mass spectrometer.

(c) Modules - Applicable cabling, line and tank tests, as above, will be performed on modules during and/or after manufacturing buildup. Modules tested will vary from relatively small pneumatic units to major assemblies consisting of a complete cabin-nose section. Module testing is designed so that upon final assembly, there will be no requirements to repeat the tests to the same level. Next assembly testing is to be mainly concerned with validation of interfaces. Tests of modularized components will be deferred until the subsystem is completed on the next assembly for cases where complex and expensive simulators are required to accomplish the test in a module level.

Installation Acceptance - As components and subassemblies are installed in the vehicle, testing will be accomplished to verify proper installation. Subsystems and components will be functionally checked and operated only to the extent necessary to verify interfaces and to provide support for the manufacturing installation process. For example, the welding of installed lines may require the actuation of onboard valves in order that the proper weld atmosphere can be established and that, subsequent to welding, proof pressure can be applied. Tests and operations of this type will be performed at the Michoud Assembly Facility and at the final assembly facility at KSC.

Subsystem Acceptance - After the manufacturing installations of subsystems and their interfaces are completed, tests of entire subsystems are performed that check proper installation integrity, function and operation of each subsystem. (Reference Paragraph 5).

Combined Subsystems Acceptance - Upon completion of individual subsystems tests, an all-up systems test will be performed where all subsystem interfaces with the vehicle and other subsystems are validated and checked out. All subsystems are tested in sequence (as controlled by the onboard DMS) to establish operational readiness and check that all elements will function in the proper sequence for flight.

An electromagnetic compatibility test will be conducted on each vehicle, with all systems as nearly as possible in flight configuration, in order to determine that any manual switch operation, data bus sequences, or mechanical sequences (that are performed in flight) will not generate spurious signals on the data bus or cause dropouts of data which would affect the overall operation of the vehicle.

Preflight Tests - A series of ground tests is performed to check proper operation of all subsystems that will operate, or be called upon to operate, during a horizontal flight. Airbreathing propulsion engines will be run up and their performance checked. The DMS will be used for onboard control and monitoring during flight. For early development vehicles, emphasis will be placed on the proper operation of the DMS and flight test instrumentation. The propellant conditioning system will be operated and checked out. APU's will be started and operations checks of the APU's, hydraulic and electrical subsystems made. An overall avionics systems test using onboard computer will be made either on an end-to-end or open loop basis (in the case of comm-navaids). The development flight test equipment will be calibrated and open loop operation to the site telemetry facility will be verified.

After all subsystems have been checked with the vehicle in a stationary position, taxi tests will be performed to demonstrate ground handling characteristics, braking, and steering systems.

Deferred Acceptance Testing - As previously described in Paragraph 5, certain subsystem, notably the propulsion subsystems, require testing subsequent to the initial horizontal takeoff of each booster to properly ascertain acceptability. For these cases, subsystem acceptance testing may be integrated with the horizontal and vertical flight test programs. For example, the Flight Readiness Firings that form a part of the vertical flight test program of Space Shuttle S/N 1 and S/N 2 also provide the testing information for acceptance. Flight Readiness Firings of the non-vertical flight test vehicle (booster S/N 1) will be performed solely for the purpose of vehicle acceptance.

7.4 Horizontal Flight Test

7.4.1 Flight Development and Verification Test Requirements - This section sets forth the requirements applicable to booster horizontal takeoff (HTO) flight tests. Orbiter horizontal takeoff flight test requirements are presented in Section C, Paragraph 7.4.1 and vertical takeoff test requirements are presented in Section A, Paragraph 7.5.

7.4.1.1 Purpose and Intent - Flight testing of the booster in the horizontal takeoff flight regime shall be employed to the extent necessary to verify operational capability, and where verification cannot be obtained more economically from ground tests or vertical takeoff tests.

7.4.1.2 Objectives - The prime objective of booster horizontal takeoff flight tests shall be to verify the cruiseback and landing phase and the ferry flight phase of the booster mission.

7.4.1.3 Requirements - The requirements applicable to the booster horizontal takeoff (HTO) flight tests are contained in Figure 7.4-1.

BOOSTER HTO FLIGHT TEST REQUIREMENTS

	TEST REQUIREMENTS	JUSTIFICATION
(I)	Flight Objectives - The number and types of objectives assigned to an individual flight shall be chosen to yield the maximum amount of useful engineering data and test time consistent with safe flight and efficient conduct. Any specific flight may embody a number of individual tests on different subsystems.	Cost and time considerations.
(II)	Location of Tests - Booster horizontal takeoff flight tests shall be conducted at the final assembly or operational site and at Edwards Air Force Base, California.	Initial tests must be conducted at final assembly site for cost considerations. EAFB is required for envelope expansion, airstarting, high angle of attack tests and other tests of a high risk

FIGURE 7.4–1

BOOSTER HTO FLIGHT TEST REQUIREMENTS (CONTINUED)

TEST REQUIREMENTS	JUSTIFICATION
	nature where a large landing area such as the dry lake bed can be used for emergency landings.
(III) <u>Flight Test Data Acquisition System</u> -	
(1) A minimum scar flight test data acquisition system comprising onboard recording and telemetry capabilities shall be installed in each test vehicle. These systems will complement and interface with the production avionics data systems. The data acquisition system for the boosters shall be installed by the booster contractor prior to initial flights.	The development and verification flight test program will require a data acquisition capability in excess of that required for operational Space Shuttle.
(2) Data processing and analysis procedures shall provide real time display and monitoring for mission control and safety, preliminary data for decision making, and final data reports.	Data processing and analysis must be conducted in a timely and economical manner to satisfy program objectives.
(IV) <u>Test Vehicles</u> - Flight development and verification testing in the horizontal takeoff regime shall be constrained to the first three boosters constructed. Modifications to test vehicles to perform development and verification flights shall be so designed, fabricated, and installed that ready conversion and refurbishment can be made to the operational configuration following flight tests. Specific modifications to the test vehicles for HTO flight tests will be designed, fabricated, and installed by the booster contractor. These shall consist of the following:	Cost considerations.
(1) <u>Crew Escape System</u> - A crew escape system suitable for emergency egress from the vehicle in the subsonic, low altitude flight regime shall be provided in each of the booster test vehicles	This is a crew safety consideration.

FIGURE 7.4–1 (Cont.)

BOOSTER HTO FLIGHT TEST REQUIREMENTS (CONTINUED)

TEST REQUIREMENTS	JUSTIFICATION
prior to initial flights by the booster contractor.	
(2) Antispin Device - Until the transition handling characteristics of the booster have been determined, no flights in the transition regime shall be made without an approved antispin device installed ready for use. The antispin device shall be designed to fit within the normal contour of the vehicle and so that the possibility of fouling controls before or after operation is reduced to a minimum. The functional operation of the device will be demonstrated prior to commencing vertical testing.	This is a vehicle safety consideration.
(V) Specific Requirements (booster HTO tests) -	
(a) Prerequisites -	
(1) Ground verification and certification of flightworthiness requirements stipulated in Paras. (TBD) shall be fulfilled as prerequisites to HTO tests.	This is a vehicle safety consideration.
(2) Ground verification of equipment in Criticality Category 1 used in horizontal flight is required prior to HTO tests.	This is a safety consideration.
(b) Minimum Requirements - Preferry Shakedown -	
(1) Subject vehicle and subsystems to a minimum of three hours flight time.	This is a time and cost consideration and is aimed at eliminating need for maintenance and repairs at off-site locations during ferry.
(2) Evaluate flying qualities and performance of booster under limited flight conditions for	

FIGURE 7.4-1 (Cont.)

BOOSTER HTO FLIGHT TEST REQUIREMENTS (CONTINUED)

TEST REQUIREMENTS	JUSTIFICATION
ferry under VFR/escort conditions.	
(c) <u>HTO Test Requirements Which Must Be Completed Prior to VTO Tests</u> -	
(1) Demonstrate safe and acceptable flying qualities throughout the nominal altitude-speed envelope required to return to the launch site from transition.	These minimum requirements are defined to provide a level-of-confidence for initial VTO flight recovery operations under ideal return conditions.
(2) Demonstrate structural integrity of the vehicle in this regime in the cruiseback and landing configuration.	
(3) Demonstrate satisfactory air-breathing propulsion system operation in this regime, including engine airstarting.	
(4) Assess the booster vehicle's airbreathing cruise performance sufficiently to verify design mission profiles for cruise-back and landing.	
(5) Assess the booster vehicle's landing approach and landing performance and characteristics to verify and refine operational procedures and techniques.	
(6) Demonstrate satisfactory operation of communications and navigation subsystems in the cruiseback and landing flight regime.	
(7) Demonstrate satisfactory operation of any other subsystem required for operation in the cruiseback and landing flight regime.	

FIGURE 7.4–1 (Cont.)

BOOSTER HTO FLIGHT TEST REQUIREMENTS (CONTINUED)

TEST REQUIREMENTS	JUSTIFICATION
(8) Functionally evaluate any subsystem to be used in the ascent entry and transition phases which can be usefully and practically evaluated in the subsonic flight regime.	
(d) <u>Minimum Requirements Prior to Operational Capability</u> -	
(1) Demonstrate safe and acceptable flying qualities throughout the required operating envelope for the ferry configuration.	Most economical method of proving system.
(2) Demonstrate structural integrity of the vehicle in this regime and configuration.	
(3) Verify airbreathing propulsion operation throughout the required ferry operating envelope.	
(4) Verify flight profiles for ferry.	
(5) Verify acceptable takeoff and landing performance.	
(6) Verify satisfactory operation of communications and navigation subsystems in the ferry configuration.	
(7) Verify satisfactory operation of all other subsystems utilized in ferry flight mode.	

7.4.2 <u>Flight Development and Verification Approaches (Booster)</u>

7.4.2.1 <u>General</u> - Space Shuttle flight testing is planned to be accomplished in three time-related parts, as described in Section A, Paragraph 7.5. This section presents those flight tests involving the booster as a single element, which are

FIGURE 7.4–1 (Cont.)

termed Booster Horizontal Takeoff (HTO) flight tests. These approaches are designed to meet the requirements listed in Figure 7.4-1.

Booster flight testing in the prelaunch, launch, ascent, entry and transition phases will be a part of mated and vertical flight vehicle and is found in Section A, Paragraph 7.5, Vertical Takeoff (VTO) flight tests.

The horizontal takeoff, airplane flight mode will be utilized to evaluate and verify booster performance for the cruiseback, landing, and ferry mission phases. This mode of testing in these flight regimes is more economical for the verification of applicable subsystems and booster performance, and removes most of the unknown factors from the posttransition flight regimes prior to vertical flight. The estimated horizontal booster flight test program will comprise 438 flight hours, utilizing three boosters over a total period of 34 vehicle months. Testing will be conducted at Kennedy Space Center (KSC), Florida, and Edwards Air Force Base (EAFB), California.

Development and verification testing will be integrated in the overall flight test approach. The flight verification of specification test requirements will be documented as it is attained. The repetition of verification flight conditions for demonstration/verification purposes will not be required.

The primary objective of the booster horizontal flight test program is to verify vehicle characteristics and subsystem operation in the cruise back and landing and the ferry flight mission phases. Functional evaluation of subsystems utilized in other mission phases such as ascent, entry, etc., will also be conducted where feasible and required or economically justified.

This objective subdivided into its component characteristics and subsystem objectives, can be time phased to program milestones as follows:

- o Testing prior to ferrying the vehicle to the prime horizontal test site
- o Testing prior to the first manned orbital mission

- Testing prior to Operational Capability (OC)

The booster horizontal flight test program has been structured to accomplish the testing required prior to each of these milestones. Development and verification flight test aspects of the booster subsystems are presented in the respective subsystem test descriptions in Section B, Paragraph 4.0 and 5.0.

7.4.2.2 Booster Configuration and Schedule - The booster horizontal flight test plan is shown in Figure 7.4-2 (VTO tests are included for clarity). Three booster vehicles will be utilized in the flight development and verification test program. The booster horizontal flight test program is concentrated primarily on one test vehicle (booster S/N 1) with a limited amount of procedural and subsystem verification testing on the remaining flight test boosters.

All of the flight test boosters will be refurbished upon completion of their test requirement and returned to service as operational vehicles.

7.4.2.2.1 Booster S/N 1 - The first booster to fly will be configured with production subsystems whenever possible. However, certain subsystems not required for horizontal flight test, or not available for installation, will be deferred until the mid-test vehicle update or the preoperational refurbishment period. These might include such items as the attitude control engines, the airbreathing engines space modifications, and portions of the avionics, thermal protection, and environmental control systems. Simulators will be installed in place of the main propulsion system rocket engines. Provisions, such as brackets, wire bundles, lines and piping, etc., for deferred subsystems will be installed prior to first horizontal flight. This approach satisfies the program level 1 requirement for first horizontal flight in June 1976, and allows early assessment of basic vehicle airframe and flight characteristics, while reducing peak funding levels by deferring subsystems development. The booster's configuration will be sufficiently representative so that horizontal flight test results will be applicable to the

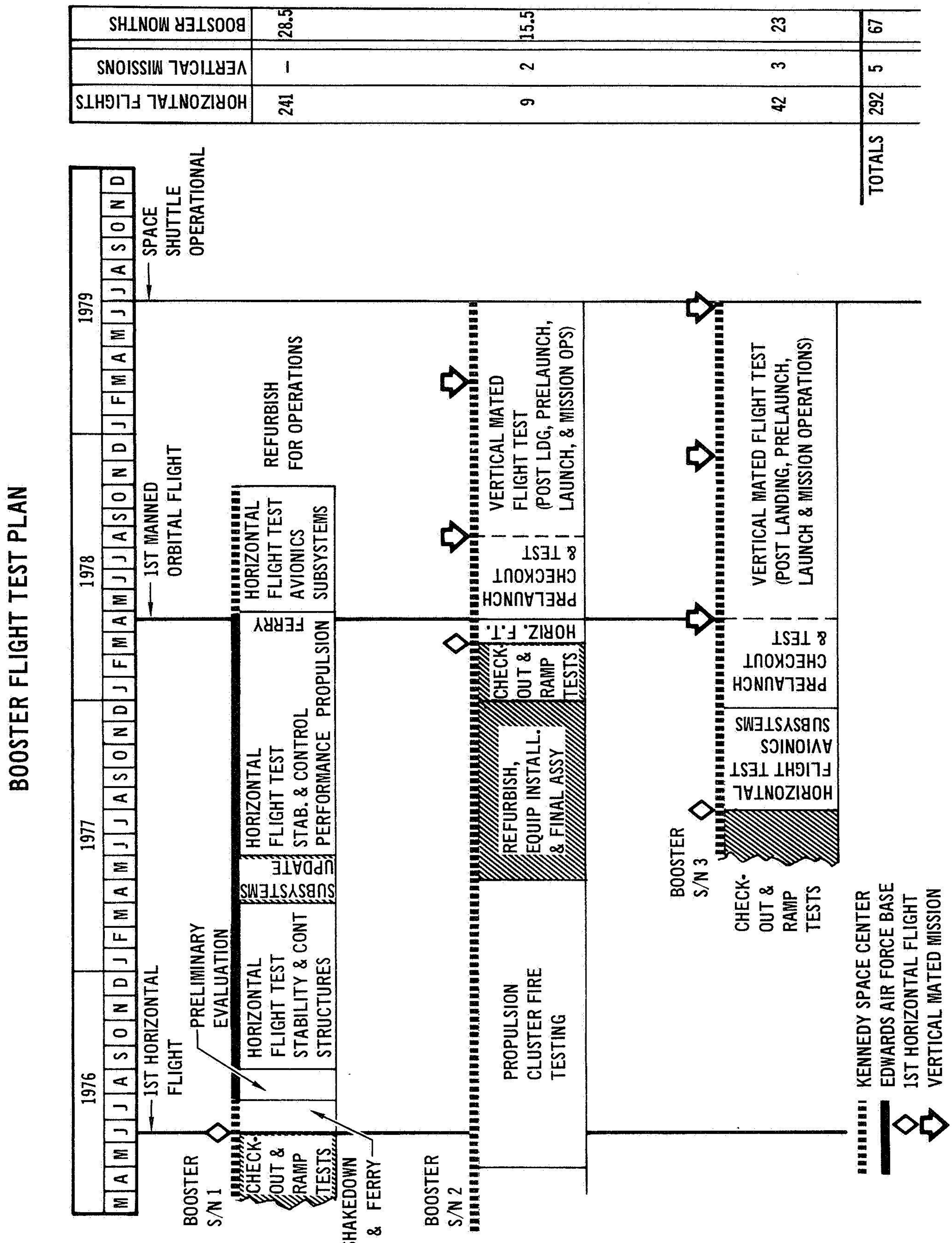

BOOSTER FLIGHT TEST PLAN
1976
1977
1978
1979
M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1ST HORIZONTAL FLIGHT
1ST MANNED ORBITAL FLIGHT
SPACE SHUTTLE OPERATIONAL
BOOSTER S/N 1
CHECK-OUT & RAMP TESTS
SHAKEDOWN & FERRY
PRELIMINARY EVALUATION
HORIZONTAL FLIGHT TEST STABILITY & CONT STRUCTURES
SUBSYSTEMS UPDATE
HORIZONTAL FLIGHT TEST STAB. & CONTROL PERFORMANCE PROPULSION
FERRY
HORIZONTAL FLIGHT TEST AVIONICS SUBSYSTEMS
REFURBISH FOR OPERATIONS
BOOSTER S/N 2
PROPULSION CLUSTER FIRE TESTING
REFURBISH, EQUIP INSTALL. & FINAL ASSY
CHECK-OUT & RAMP TESTS
HORIZ. F.T.
PRELAUNCH CHECKOUT & TEST
VERTICAL MATED FLIGHT TEST (POST LDG, PRELAUNCH, LAUNCH, & MISSION OPS)
BOOSTER S/N 3
CHECK-OUT & RAMP TESTS
HORIZONTAL FLIGHT TEST AVIONICS SUBSYSTEMS
PRELAUNCH CHECKOUT & TEST
VERTICAL MATED FLIGHT TEST (POST LANDING, PRELAUNCH, LAUNCH & MISSION OPERATIONS)
HORIZONTAL FLIGHTS
VERTICAL MISSIONS
BOOSTER MONTHS
241
–
28.5
9
2
15.5
42
3
23
TOTALS
292
5
67
KENNEDY SPACE CENTER
EDWARDS AIR FORCE BASE
1ST HORIZONTAL FLIGHT
VERTICAL MATED MISSION

FIGURE 7.4–2

production configured vehicles. A short lay-up for subsystem updating is scheduled so that required horizontal flight testing, with production subsystems, may be obtained prior to commencing vertical flight testing.

Flight test modifications will consist of the development flight instrumentation system and crew escape system. A special flight test vehicle modification (additional airbreathing engines, solid rockets, etc.--booster S/N 1 only) may be required to augment the thrust of the airbreathing engines for the airstart testing described in Section B, Paragraph 5.2.3.

The booster horizontal flight test program will commence with a preliminary, shakedown flight period at the final assembly site, Kennedy Space Center (KSC), Florida. The integrated vehicle ground development, verification, and acceptance testing, etc., Section B, Paragraph 7.2 and 7.3) will be completed prior to flight. A brief series of taxi runs (two or three test periods) will be conducted at increasing velocities to evaluate ground handling characteristics - steering, braking and stopping. Landing gear and deceleration system operation will be verified at this time only to the extent necessary to perform the initial series of test flights.

The evaluation conducted at KSC will constitute that part of the horizontal test program required prior to the first, and minor, program milestone--ferrying the airplane to the prime horizontal test site. Vehicle flight handling qualities and performance during takeoff, landing, and cruise flight will be evaluated and the absence of unsafe flight characteristics will be verified (approximately 9 flight hours required). This evaluation satisfies the requirement No.V(b) 1 & 2 listed in Figure 7.4-1.

The booster will then be ferried to the primary horizontal flight test site at Edwards Air Force Base. The ferry flights will be flown under VFR flight conditions and the airplane will be accompanied by a chase aircraft, for flight safety consideration and the transport of ground support equipment and personnel. Military airfields will be utilized for intermediate stops. A preliminary ferry route with 5 stops, maximum stage distance of 440 nautical miles, has been postulated and is shown in Figure 7.4-3. Subsystem functional operational data and experience will be obtained on these ferry flights.

The preliminary flight evaluation will be completed following arrival at Edwards AFB. This booster will then be utilized as the primary horizontal flight test booster vehicle for a period of approximately 27.5 months, including a brief mid-test lay-up for subsystem update. The final portion of this horizontal testing will be conducted at KSC subsequent to the return ferry flight.

7.4.2.2.2 Booster S/N 2 - This booster fuselage will be utilized as a cluster fire propulsion test article for about 12 months. This testing will be conducted on the operational launch site at Kennedy Space Center (KSC). The fuselage will then be returned to manufacturing for refurbishment, completion of booster assembly, and the installation of flight rated main propulsion engines. Flight test modifications to this vehicle will include the development flight instrumentation system, a crew escape system, and a spin recovery/pitch augmentation device. In other respects, this booster will be in the operational configuration. Upon completion of ground checkout, ramp and acceptance testing, this vehicle will become the third booster to fly in the horizontal mode in March 1978. After approximately one month of horizontal test flying at KSC, this vehicle will be placed on vertical test flight status, being paired with orbiter S/N 2. This booster is scheduled for the second development vertical launch and will be utilized in the vertical test program until July 1979.

7.4.2.2.3 Booster S/N 3 - The third booster in the manufacturing process will be configured with production, qualified subsystems. Flight rated main propulsion rocket engines will be installed. Flight test modifications to this vehicle will

SPACE SHUTTLE FLIGHT TEST PLAN
BASELINE FERRY PLAN

FLIGHT LEG	DISTANCE ~N.MI.	RUNWAY DIMENSIONS ~FEET	FIELD ELEVATION ~FEET	RUNWAY WT. BEARING CAPACITY – POUNDS (TWIN TANDEM GEAR)
CAPE KENNEDY		TO BE CONSTRUCTED	APPROX S.L.	TO BE CONSTRUCTED
TO EGLIN AFB	340	12,000 x 300	85	500,000
TO BLYTHEVILLE AFB	440	11,600 x 300	255	455,000
TO SHEPPARD AFB	440	13,100 x 300	1015	540,000
TO BIGGS AAF	420	13,572 x 300	3947	440,000
TO YUMA MCAS	420	13,300 x 200	213	410,000
TO EDWARDS AFB	210	15,000 x 300	2302	560,000

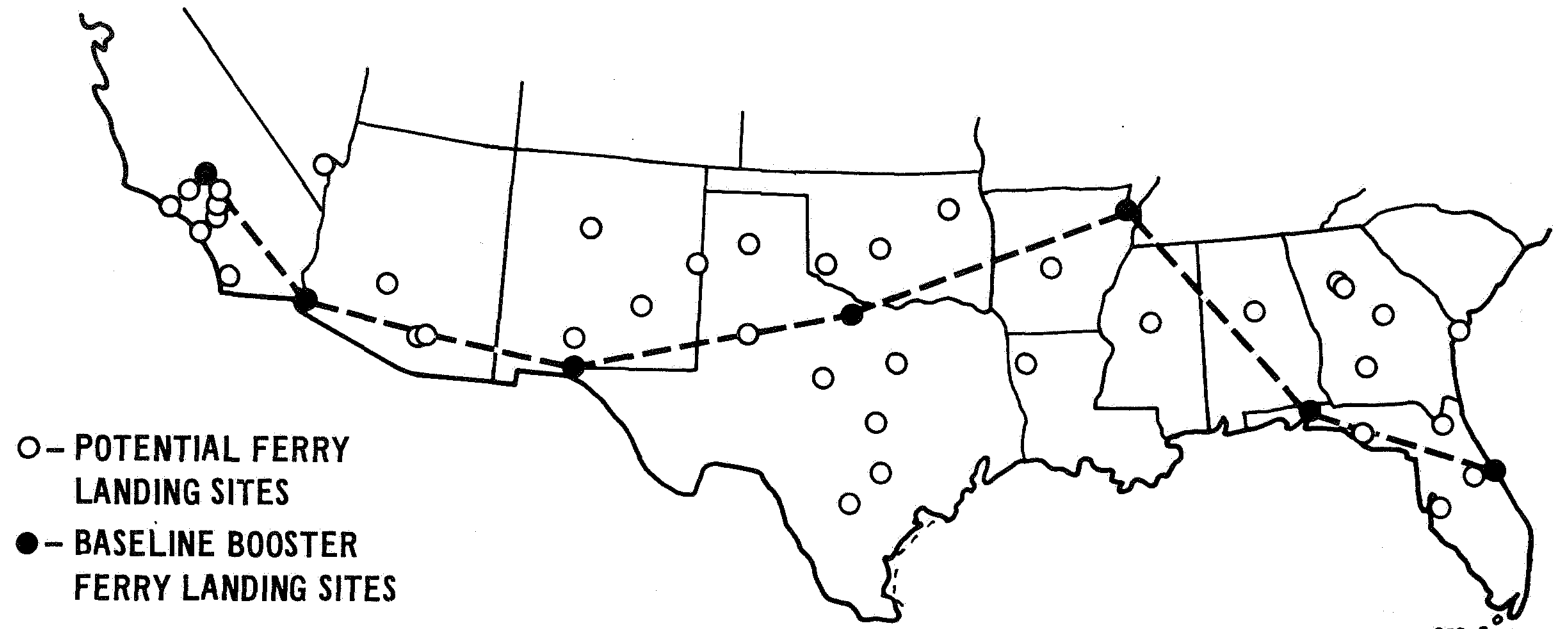


FIGURE 7.4–3

include the development flight instrumentation system, a crew escape system, and a spin recovery/pitch augmentation device. Upon completion of ground checkout, ramp, and acceptance testing, this vehicle will become the second booster to fly horizontally. After 4.5 months of horizontal flight testing at KSC, this vehicle will be placed on vertical test flight status, being paired with orbiter S/N 3. The first program vertical launch (mated, manned, orbital), preceded by a period of ground checkout and testing, is scheduled for April 1978. This booster is scheduled for three manned orbital launches with its utilization in the vertical test program completing in July 1979.

7.4.2.3 Flight Summary - This section describes the minimum amount and categories of horizontal flight testing to satisfy the booster HTO flight test requirements. The planning process for developing a flight test plan is summarized in Figure 7.4-4.

The Required Flight Hours are seen to be based primarily on the test requirements and past experience. A major function in determining the minimum flight hours required, is the flight test approach philosophy used to determine program scope. The effects of a study of several alternate approaches -

(a) Verification with Buildup and Modest Development - A program wherein confidence in the vehicle's ability to demonstrate design limit conditions is high and where an incremental approach is used to achieve critical conditions. In addition (based on experience) a certain amount of time is allocated for adjusting, changing gains, "tweeking", and reevaluating subsystems performance following changes.

(b) Verification with Buildup - A program where confidence in the vehicle's ability to demonstrate design limit conditions is high and where an incremental approach is used to achieve critical conditions.

DEVELOPMENT OF REQUIRED
HORIZONTAL FLIGHT TEST HOURS

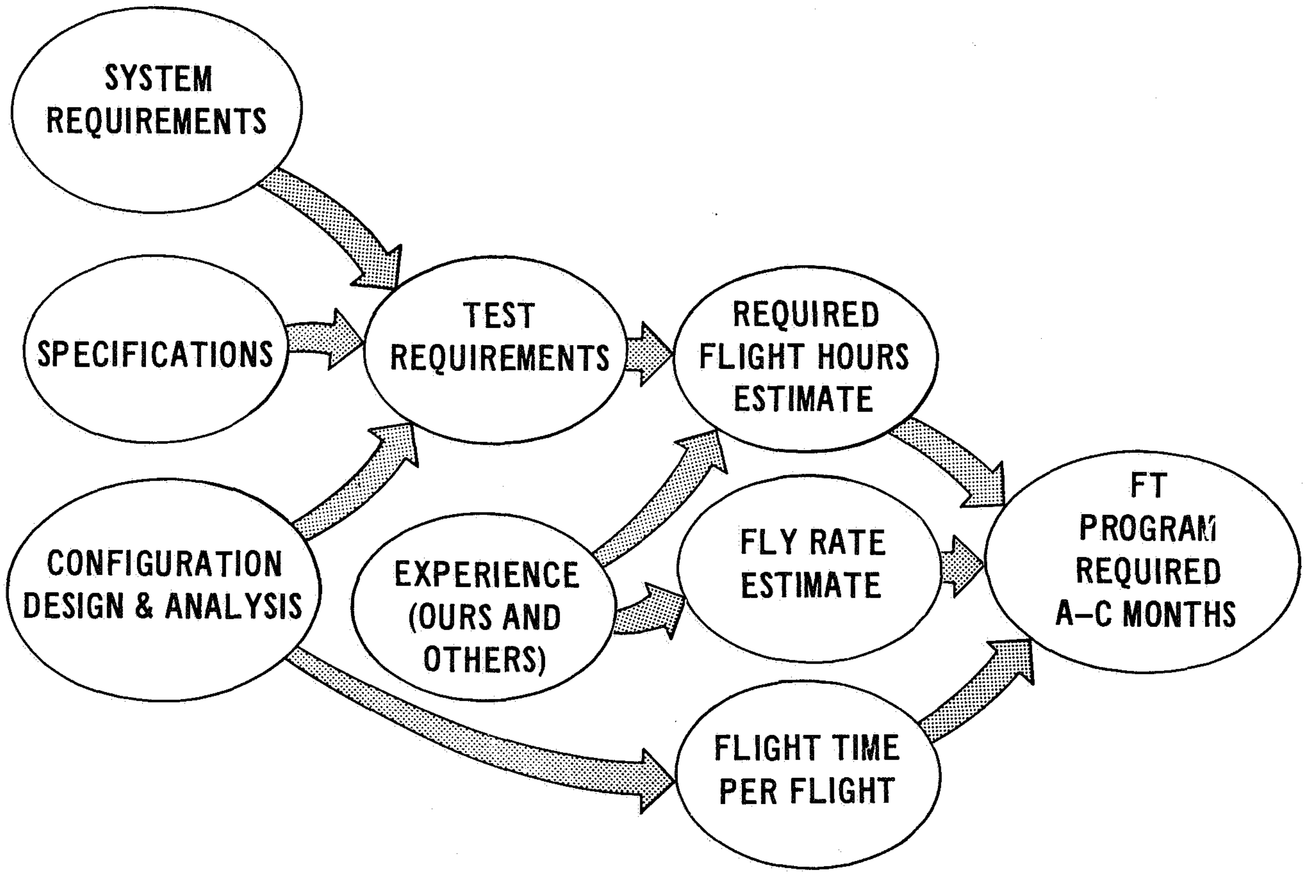


FIGURE 7.4–4

(c) Verification Spot Check - This term is applied to that type of program wherein confidence in the vehicle's ability to demonstrate design limit conditions without any failures is extremely high based on previous experience with a very similar configuration. In this program approach, only a few of the most critical design conditions based on analysis would be flown.

(d) Verification Only - is used to describe a program wherein confidence in the vehicle's ability to demonstrate design limit conditions without any failures is extremely high based on previous experience with a similar configuration and where only the design limit conditions are flown for demonstration purposes.

are summarized in Figure 7.4-5. It is our belief that philosophy (a) - verification with buildup and modest development - represents a realistic approach to be used in the determination of the scope of the booster horizontal flight test program.

The minimum booster flight hour requirements, utilizing this philosophy are tabulated in Figure 7.4-6. The flight hours have been categorized by flight characteristics and subsystem categories. The flight test requirements, listed in Figure 7.4-1 are cross referenced in adjacent columns to their respective minimum flight hours. The principles of concurrency of test objectives and the optimizing of flight time utilization, as required by Test Requirement (I), Figure 7.4-1, has been incorporated, i.e., the majority of ECLS and power supply testing will be concurrent with other flight tests, some test data will be collected on ferry flights, APU and thermal protection testing will be largely concurrent, etc. The approximate minimum amount of testing required to be completed at the various horizontal flight test program milestones described in Paragraph 7.4.2.1 is also given in Figure 7.4-6. The planned horizontal flight testing prior to ferry to the primary test site (approximately nine flight hours) has been included as part

HORIZONTAL FLIGHT TEST ALTERNATIVES
Booster

PROGRAM SCOPE	ESTIMATED FLIGHT HOURS BY TEST CATEGORY					ESTIMATED TOTAL FLIGHT HOURS
	AERO	STRUCT	PROPUL-SION	EQUIP-MENT	MISC	
VERIFICATION WITH BUILDUP AND MODEST DEVELOPMENT	156	25	53	184	20	438
VERIFICATION WITH BUILDUP	103	25	25	90	20	263
VERIFICATION ONLY	67	12	10	32	0	121
VERIFICATION SPOT CHECK	24	5	5	16	0	50

BASELINE

FIGURE 7.4–5

BOOSTER HORIZONTAL FLIGHT TEST

TEST CATEGORY	MINIMUM REQUIREMENTS PRIOR TO FIRST VERTICAL FLIGHT		MINIMUM REQUIREMENTS PRIOR TO OPERATIONAL CAPABILITY		TOTAL FLIGHT HOURS REQUIRED
	FLIGHT HOURS	FIG 7.4–1 REQ NO.	FLIGHT HOURS	FIG 7.4–1 REQ NO.	
FLIGHT CHARACTERISTICS					
• PRELIMINARY EVALUATION					
• HANDLING QUALITIES; STABILITY & CONTROL	10	(V)b; (V)c			10
• TAKEOFF & LANDING PERFORMANCE	7				7
• SUBSYSTEM EVALUATION	2				2
• CRUISE PERFORMANCE	1				1
• STABILITY & CONTROL					
• HANDLING QUALITIES; MANEUVERING CAPABILITIES (BASIC MANUAL FBW)	17	(V)c1	15	(V)d1	32
• DYNAMIC STABILITY	3		2		5
• TRIM CHARACTERISTICS & STATIC STABILITY	3		2		7
• ENGINE OUT CHARACTERISTICS	7		3		10
• UNUSUAL ATTITUDES & TURBULENCE	2				2
• PERFORMANCE					
• TAKEOFF			5	(V)d5	5
• LANDING	15	(V)c5	5	(V)d5	20
• FLIGHT	10	(V)c4	5	(V)d4	15
• BUFFET & MINIMUM CONTROL	15	(V)c1	5	(V)d1	20
• AIRSPEED CALIBRATION	12	(V)c7	8	(V)d7	20
AIRFRAME GROUP					
• STRUCTURES					
• FLIGHT LOADS SURVEY	20	(V)c2			20
• STRUCTURAL VERIFICATION	5				5
• FLUTTER; AEROELASTIC EFFECTS; VIBRATION, ACOUSTIC & THERMAL ENVIRONMENT (CONCURRENT)				(V)d2	
• LANDING & RECOVERY					
• DEVELOP & VERIFY BRAKES, ANTI-SKID	5	(V)c5; c7			5
• LOADS SURVEY (CONCURRENT)		(V)c2		(V)d2	

FIGURE 7.4–6

BOOSTER HORIZONTAL FLIGHT TEST (Continued)

TEST CATEGORY	MINIMUM REQUIREMENTS PRIOR TO FIRST VERTICAL FLIGHT		MINIMUM REQUIREMENTS PRIOR TO OPERATIONAL CAPABILITY		TOTAL FLIGHT HOURS REQUIRED
	FLIGHT HOURS	FIG 7.4–1 REQ NO.	FLIGHT HOURS	FIG 7.4–1 REQ NO.	
PROPULSION GROUP					
• AIR BREATHING PROPULSION					
• ENGINE HANDLING & CONTROL	17	(V)c3			17
• DUCT RECOVERY (ENGINE FACE TEMP & PRESSURE SURVEY)			10	(V)d3	10
• AIRSTARTS	22	(V)c3			22
• FUEL SYSTEM (CONCURRENT)		(V)c3			
• ANTI-ICING PERFORMANCE	4	(V)c3			4
AVIONICS GROUP					
• GUIDANCE AND NAVIGATION					
• IMU	12	(V)c6; c8			12
• COMMUNICATIONS & NAVAIDS					
• DME, ILS	9	(V)c6; c8	6	(V)d6	15
• RADAR ALTIMETER	10	(V)c6; c8	15	(V)d6	25
• S-BAND, UHF, INTERCOM (CONCURRENT)					
• FLIGHT CONTROL ELECTRONICS					
• AUTO-PILOT PERFORMANCE	10	(V)c1; c7	24	(V)c8; d7	34
• AIR DATA SENSORS (CONCURRENT)		(V)c1; c7		(V)d1; d7	
• AUTOMATIC APPROACH & LANDING	25	(V)c1;c5;c7	50	(V)c/d1;d5,d7	75
• DATA MANAGEMENT – SOFTWARE (CONCURRENT)		(V)c7; c8		(V)d7	
• AVIONICS DISPLAYS & CONTROLS		(V)c7; c8			
• PERFORMANCE & SUITABILITY (MUCH CONCURRENT)			8	(V)d7	8

FIGURE 7.4–6 (Cont.)

BOOSTER HORIZONTAL FLIGHT TEST (Continued)

TEST CATEGORY	MINIMUM REQUIREMENTS PRIOR TO FIRST VERTICAL FLIGHT		MINIMUM REQUIREMENTS PRIOR TO OPERATIONAL CAPABILITY		TOTAL FLIGHT HOURS REQUIRED
	FLIGHT HOURS	FIG 7.4–1 REQ NO.	FLIGHT HOURS	FIG 7.4–1 REQ NO.	
CREW STATION GROUP					
• ENVIRONMENTAL CONTROL (MUCH CONCURRENT)		(V)c7;c8	8	(V)d7	8
• CREW SYSTEMS, DISPLAYS & CONTROLS (CONCURRENT)					
POWER SUPPLY GROUP					
• ELECTRICAL POWER (MAINLY CONCURRENT)			1		1
• HYDRAULIC POWER (MAINLY CONCURRENT)			1		1
MISCELLANEOUS & FERRY					
• FERRY KSC/FRC/KSC	9		8		17
• MISCELLANEOUS			3		3
SUBTOTAL	253		185		
TOTAL FLIGHT HOURS					438

FIGURE 7.4–6 (Cont.)

of Preliminary Evaluation Flight Characteristics testing required prior to first vertical flight.

The estimated flight hours required for the horizontal flight test program are less than those required for recent large commercial and military airplanes, as compared in Figure 7.4-7. This reduction is based on the following assumptions:

- o Verification of specification compliance will be based primarily on the demonstration of safe and adequate mission capabilities, rather than an absolute numerical compliance. Flight effort has not been budgeted to develop and demonstrate small performance or other numerical compliance "fixes".
- o Development and verification test flying will be integrated. There will be no repeat or special flying for customer demonstration.
- o The flight envelope will be reduced.
- o Ground testing of subsystems and components will be more rigorous than in normal airplane practice.

The Fly Rate estimate is based on past experience with various airplane types and an assessment of relative design complexities, performance envelopes, and degree of configuration conventionality. Fly rates for a variety of recent airplanes during their first year of flight testing as a function of vehicle complexity assessment are shown in Figure 7.4-8.

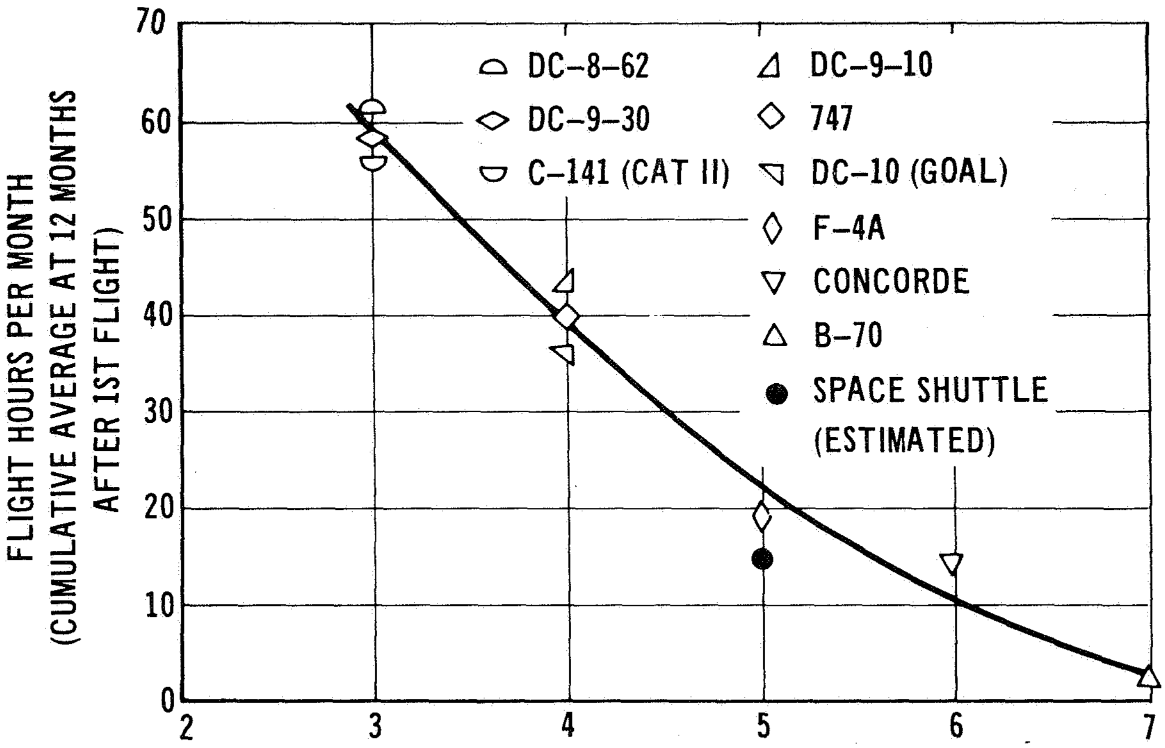
Based on design cruise performance, an average flight time of 1 1/2 hours has been postulated for test program planning purposes. It has also been postulated that an average overall testing rate of nine flights per month should be attainable. This estimate results in an overall average test flying rate for planning purposes of 13.5 flight hours per vehicle month. This space shuttle fly rate estimate, plotted on Figure 7.4-8, appears conservatively realistic, and has been utilized tc develop our flight test plans. This flight rate considers vehicle/data system refurbishment

COMPARISON OF LARGE SUBSONIC VEHICLE TEST PROGRAMS
Flight Hours

	MILITARY		COMMERCIAL	SPACE SHUTTLE	
	LOCKHEED C–5A	PROPOSED C–5A	DC–10	BOOSTER	ORBITER
FLIGHT CHARACTERISTICS	–	147	275	156	130
STRUCTURES	–	346	60	30	30
PROPULSION	–	204	120	53	46
AVIONICS	–	610	255	169	166
SYSTEMS	–	325	225	10	10
MISCELLANEOUS	–	105	115	20	20
TOTAL CONTRACTOR	2,219	1,764	1,050	438	402
FAA			450	–	–
CAT II	4,590	4,170	–	–	–
TOTAL	6,809	5,934	1,500	438	402

FIGURE 7.4–7

FLY RATE VS COMPLEXITY



RELATIVE COMPLEXITY

FLY RATE COMPLEXITY FACTOR
How Computed

COMPLEXITY = FLIGHT ENVELOPE FACTOR + SYSTEMS FACTOR

FLIGHT ENVELOPE FACTORS	SYSTEMS FACTORS
1 SUBSONIC 2 TRANSONIC 3 SUPERSONIC 4 SUPERSONIC CRUISE	1 PROVEN SYSTEMS 2 NEW BUT STATE-OF-ART 3 NOVEL SYSTEMS OR METHODS 4 MULTIPLE NOVEL SYSTEMS

ADD 1 FOR NOVEL
OR HAZARDOUS CONFIGURATION
OR FLIGHT REGIME

FIGURE 7

and minor modification periods as well as actual flight status times, but not a major update period such as the two month subsystem update period required by booster S/N 1.

The estimates of required flight hours and flight hour rate per month establishes the total requirement of 32 booster vehicle months of horizontal flight testing. The distribution of those flight hours among the three test boosters is shown in Figure 7.4-9. The estimated flight hours listed by test categories and collated by test vehicle, test site, and hours completed prior to first vertical flight, are presented in Figure 7.4-10.

Other major considerations in the construction of this baseline flight test plan are:

(a) Level I Requirement schedule milestones - FIRST HORIZONTAL FLIGHT, JUNE 1976
- FIRST MANNED ORBITAL FLIGHT, APRIL 1978

(b) Booster availability from manufacturing

(c) Sufficient Prelaunch checkout and testing time available prior to first vertical mission.

(d) Completion of at least the minimum number of flight test hours required prior to first vertical mission (Figure 7.4-6).

(e) Minimum number of ferry missions.

(f) Smooth vehicle loading at the test sites as much as possible (one horizontal test flight booster at a facility at a given time, if possible).

(g) Types of testing requiring a specific test site (KSC or EAFB) conducted at that site. (See Paragraph 7.4 for discussion of test site requirements).

The Baseline booster flight test plan presented in Figures 7.4-9 and 7.4-10 satisfied these requirements and considerations. Further descriptions of the horizontal

HORIZONTAL FLIGHT TEST SCHEDULE
Booster

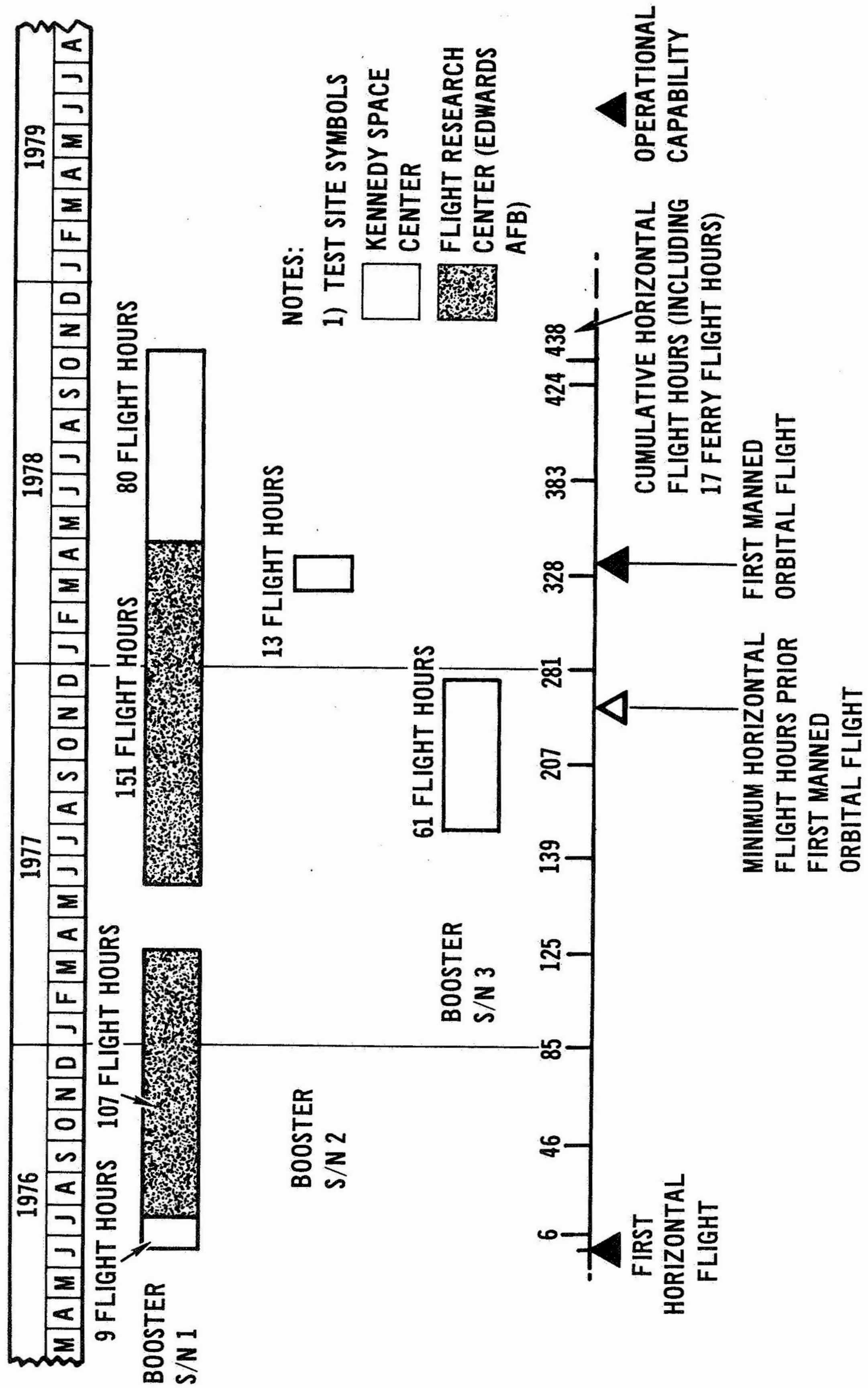


FIGURE 7.4–9

BOOSTER HORIZONTAL FLIGHT TEST

TEST CATEGORY	BASELINE PLAN – HORIZONTAL FLIGHT HOURS						
	BOOSTER VEHICLE			TEST SITE		PRIOR TO FIRST VERTICAL FLIGHT	TOTAL FLIGHT HOURS
	S/N 1	S/N 2	S/N 3	KSC	EAFB		
FLIGHT CHARACTERISTICS							
• PRELIMINARY EVALUATION	20			9	11	20	20
• STABILITY & CONTROL	56				56	56	56
• PERFORMANCE	40				40	40	40
• BUFFET & MINIMUM CONTROL	20				20	20	20
• AIRSPEED CALIBRATION	10	5	5	10	10	20	20
AIRFRAME GROUP							
• STRUCTURES	25				25	25	25
• LANDING & RECOVERY	5				5	5	5
PROPULSION GROUP							
• AIRBREATHING	53				53	53	53
AVIONICS GROUP							
• GUIDANCE & NAVIGATION			12	12		12	12
• COMMUNICATIONS & NAVAIDS	28	8	4	22	18	30	40
• FLIGHT CONTROL ELECTRONICS	69		40	89	20	53	109
• DATA MANAGEMENT – SOFTWARE (CONCURRENT)							
• AVIONICS DISPLAYS & CONTROLS	8			8			8
CREW STATION GROUP							
• ENVIRONMENTAL CONTROL (MUCH CONCURRENT)							
• CREW SYSTEMS, DISPLAYS & CONTROLS (CONCURRENT)	8			8			8
POWER SUPPLY GROUP							
• ELECTRICAL POWER (MAINLY CONCURRENT)	1			1			1
• HYDRAULIC POWER (MAINLY CONCURRENT)	1			1			1
MISCELLANEOUS & FERRY							
• FERRY KSC/FRC/KSC	17					9	17
• MISCELLANEOUS	3			3			3
SUBTOTAL	364	13	61	163	258	343	
TOTAL FLIGHT HOURS							438

FIGURE 7.4–10

flight testing is provided under the respective flight characteristics and subsystem sections (Section 4.0 and 5.0) of this report.

7.4.2.4 Flight Test Support

Test Sites and Facilities - Booster horizontal takeoff, airplane mode, flight tests will be conducted at the final assembly/operational site, Kennedy Space Center, Florida, and at Edwards Air Force Base, California. In the selection of locations for performing horizontal flight tests, the following factors were considered:

- o Test and Support Facilities
- o Experimental Test Flying Weather
- o Normal and Emergency Landing Facilities
- o Cost

Since our baseline Manufacturing plan calls for final assembly of the vehicle at KSC (which is the baseline operation site selected in our Operations Plan) it was obvious that our initial flights would be most practically performed from that site. From our past experience in airplane development, however, we were aware of and had utilized in the past, several other facilities in the United States which were specifically devoted to aircraft testing and which seemed to offer some advantages to the Space Shuttle program for subsequent flights. Specifically these sites were:

Holloman AFB, New Mexico

Naval Air Test Center, Patuxent River, Maryland

Eglin AFB, Florida

Edwards AFB, California

Of these sites, we eliminated from consideration first NATC Patuxent River, Maryland because of air traffic and population (in the vicinity) reasons. Holloman AFB and Edwards AFB offered some similar advantages but Edwards was selected as the best of these two primarily because the field elevation at Holloman (Approx. 4000' as compared to 2385 for Edwards) was felt to be sufficiently high so as to inhibit the amount of horizontal testing that could be done at this location.

The remaining sites (Eglin and Edwards) were compared with the operations/

final assembly site as shown in Figures 7.4-11 through 7.4-16 from the standpoint of existing facilities, weather, and safety considerations.

Based on these comparisons and on our own judgement, we arrived at a distribution of horizontal tests by location as shown on Figures 7.4-17 and 7.4-18.

Logistic Support - Booster horizontal flight test spares and supply support, except for specific Government furnished equipment such as main propulsion rocket engines, etc., will be the responsibility of the Booster flight test contractors.

Procedures and Training - Operational support procedures for maintenance and the post and preflight inspections associated with the airplane flight mode will be verified by utilization during the flight test program. The adequacy of operational and maintenance crew training, concepts, and staffing levels will also be verified during the flight test program, insofar as applicable in the horizontal program.

Data Processing and Analysis - The data processing and analysis subsystems will provide for the real time display and monitoring, and the reduction and presentation of engineering decision and final report data. Data will be obtained from sensors on-board the Space Shuttle, by telemetry and from on-board tape recordings as discussed in paragraph 7.5 entitled "Development Flight Instrumentation." Air Force Flight Test Center and other networks will provide space position information.

Real time data display and monitoring for mission control and flight safety purposes during the Booster horizontal test flights will be similar to current airplane flight test practices. The primary function of the monitoring is the verification of the adequacy of test conditions and an overall vehicle safety monitoring. The level of effort will be small, compared to manned orbital space flight procedures, and existing government or contractor facilities at or near Edwards Air Force Base, suitably modified, will be utilized.

TEST SUPPORT FACILITIES COMPARISON

HORIZONTAL TEST SITE

REQUIRED FACILITY \ SITE	KSC	EGLIN AFB	EDWARDS AFB
T.O. & LAND PHOTO OPTICS		X	X
TELEMETRY	X	X	X
VOICE COMMUNICATIONS	X	X	X
HANGAR/PARKING	T	X	X
SPACE POSITION & TRACKING	X	X	X
WEIGHT & BALANCE (LARGE VEHICLE)			X
THRUST CALIBRATION (TURBOJET)			X
FLIGHT INSTRUMENT CALIBRATION	X		X
DATA PROCESSING & COMPUTING	X	X	X

X AVAILABLE & ADEQUATE

T TO BE CONSTRUCTED FOR OPERATIONAL PHASE

FIGURE 7.4-11

EXPERIMENTAL TEST FLYING
WEATHER REQUIREMENTS
HORIZONTAL TEST SITE

TEST	WEATHER REQUIREMENTS
STABILITY & CONTROL	VFR PLUS SMOOTH AIR AT TEST ALTITUDE*
TAKEOFF & LANDING PERFORMANCE	LIGHT WINDS PARALLEL TO RUNWAY. ADEQUATE LIGHT & VISIBILITY FOR CAMERA COVERAGE
CRUISE PROPULSION TESTS (TRANSIENT, AIRSTARTS, ICING, ETC)	CEILING ABOVE TEST ALTITUDE, VISIBILITY TO LANDING SITE FROM TEST AREA
POWER OFF APPROACH AND LANDING	CEILING ABOVE HIGH KEY (≅25,000 FT) & VISIBILITY 15 MILES PLUS.
FERRY/CRUISE SUBSYSTEM TEST	COULD BE AS LOW AS IFR FOR PROVEN AIRFRAME/PROPULSION SYSTEM.

* FOR LOW SPEED HIGH ANGLE OF ATTACK WHEREIN LARGE ALTITUDE LOSS COULD RESULT, WOULD NOT PERFORM ABOVE AN OVERCAST.

FIGURE 7.4–12

CEILING/VISIBILITY PROBABILITY VS MONTH FOR THREE TEST SITES

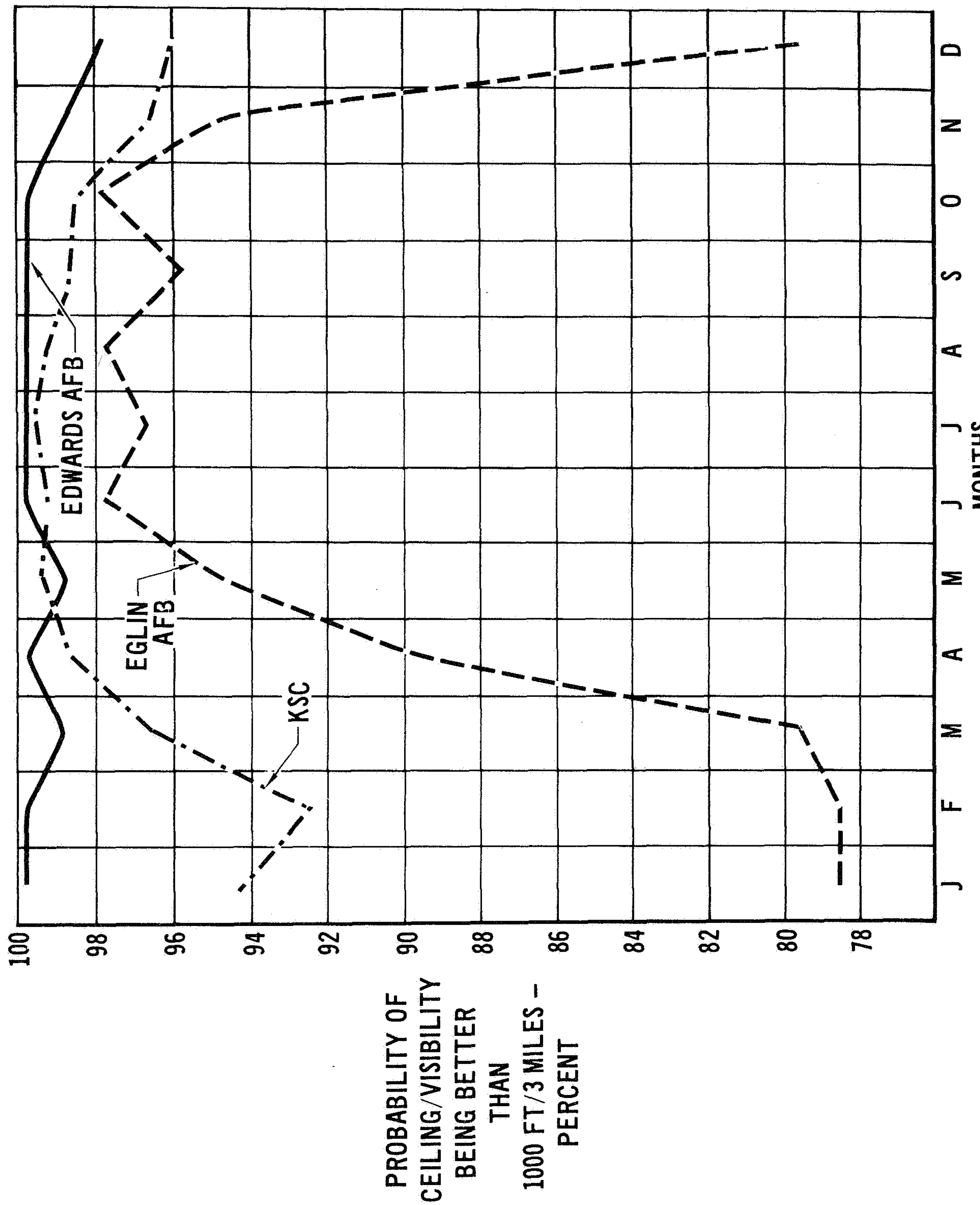


FIGURE 7.4–13

EMERGENCY LANDING SITE CRITERIA

HORIZONTAL TEST SITE

- MINIMUM OBSTRUCTIONS
- EXTRA LENGTH
- EXTRA WIDE
- ANY DIRECTION
- VISIBILITY

FIGURE 7.4–14

NORMAL AND EMERGENCY

LANDING FACILITIES COMPARISON

	KSC	EGLIN AFB	EDWARDS AFB
MAIN BASE ELEVATION RUNWAY 1 RUNWAY 2 LOAD CAPACITY (TT)	TO BE CONSTRUCTED	 85 FT 12,000 X 300 FT 10,000 X 300 FT 500,000 LB	 2302 FT 15,000 X 300 FT - 560,000 LB
OTHER AIRPORTS WITHIN 50 MILES WITH RUNWAYS 10,000 FT OR LONGER	MCCOY AFB CAPE KENNEDY SKID STRIP	TYNDALL AFB	PALMDALE GEORGE AFB CHINA LAKE NAF
NATURAL LANDING SITES WITHIN 50 MILES (OVER 10,000 FT. LONG)			ROGERS DRY LAKE HARPERS DRY LAKE MIRAGE DRY LAKE ROSAMOND DRY LAKE CUDDLEBACK DRY LAKE

FIGURE 7.4-15

AERODROME INFORMATION

	MCCOY AFB	CAPE KENNEDY SKID STRIP	TYNDALL AFB	PALMDALE	GEORGE AFB	CHINA LAKE
ELEVATION (FT)	96	9	18	2,549	2,875	2,283
RUNWAY 1 (FT)	12,000 X 300	10,000 X 300	10,000 X 200	12,000 X 200	10,000 X 150	10,000 X 200
RUNWAY 2 (FT)	12,000 X 200	-	-	12,000 X 150	9,126 X 150	9,000 X 200
LOAD CAPACITY (TT) (LB)	540,000	-	245,000	530,000	440,000	361,000

FIGURE 7.4-16

HORIZONTAL TEST LOCATIONS

TEST TYPE	RECOMMENDED SITES	
	KSC	FRC
SHAKEDOWN, ACCEPTANCE	X	
INFLIGHT VERIFICATION OF OPERATIONAL CRUISEBACK AND LANDING PROCEDURES AND NAVAIDS BOTH VEHICLE AND OPERATIONAL SITE	X	
HIGH RISK TESTING (ENGINE AIRSTARTING, ENGINE HANDLING, ENGINE OUT PERFORMANCE LIMITS OF CONTROLABILITY, HIGH ENERGY LANDING EVALUATION, BRAKING TESTS)		X

FIGURE 7.4-17

HORIZONTAL TEST HOURS DISTRIBUTION								
TEST CATEGORY	TEST VEHICLE						TEST SITES	
	BOOSTER			ORBITER			KSC	FRC
	1	2	3	1	2	3		
PRE-FERRY	9			9			18	
PRE-1ST VTO*	260	13	61	253	13	60	165	495
POST-1ST VTO	87			59			132	14
TOTAL ON SITE	347	13	61	312	13	60	297	509
FERRY	17			17				
TOTAL	438			402			840	

*PRE - 1ST VTO FIGURES INCLUDE PRE-FERRY FIGURES

FIGURE 7.4-18

7.5 Development Flight Instrumentation

7.5.1 General DFI Requirements - The Development Flight Instrumentation System must provide the following:

Requirements	Justification
1. A completely removable system leaving minimum scar weight in the vehicle.	To allow minimum payload penalty for operational flights.
2. Data for post flight analysis for performance verification of vehicle subsystems and structures.	To assure proper vehicle operation and establish functional margins.
3. Telemetry signals to ground data displays for mission control and analysis.	To allow real-time decision making and advisory by subsystem disciplines.
4. Data from the Orbiter covering periods of no ground contact.	To allow analysis should a malfunction or significant activity take place.
5. A system compatible with existing receiving and processing equipment.	To minimize the new equipment that must be purchased and maintained.
6. A flexible system - easily changed and adapted to program requirements.	To minimize program delays due to new requirements or changes in objectives.

A summary of the parameters to be monitored by the DFI is given in Figure 7.5-1.

7.5.2 Approach and Rationale - A separate overlay DFI system is provided as shown in the block diagram, Figure 7.5-2. The systems consist of:

2 UHF telemetry transmitters

2 DFI data bus systems

An FM-FM constant bandwidth high frequency data system

1 to 4 FM tape recorders

2 Digital magnetic tape recorders with high speed playback capability

The DFI systems for the Booster and Orbiter vehicles are essentially identical and consist of two distinct subsystems: a digital data bus system for the quasi-static data and an FM-FM system for the high frequency response or dynamic data. Most data will be recorded on-board; in addition, however, RF telemetry will provide real-time display of information needed for mission control and status monitoring.

SPACE SHUTTLE DFI PARAMETER SUMMARY

PARAMETER TYPE	QUANTITY	
	ORBITER	BOOSTER
HIGH FREQUENCY DATA		
VIBRATIONS	195	186
ACOUSTICAL ENERGY	24	35
LOADS – STRAINS	298	290
ACCELERATIONS	21	39
SUBTOTAL	538	550
QUASI-STATIC DATA		
TEMPERATURES	923	1691
PRESSURES	208	275
MISCELLANEOUS–QUANTITIES, LEVELS, FLOW, ETC.	97	110
EVENTS	400	310
SUBTOTAL	1628	2386
GRAND TOTAL	2166	2936

FIGURE 7.5–1

DFI SYSTEM BLOCK DIAGRAM

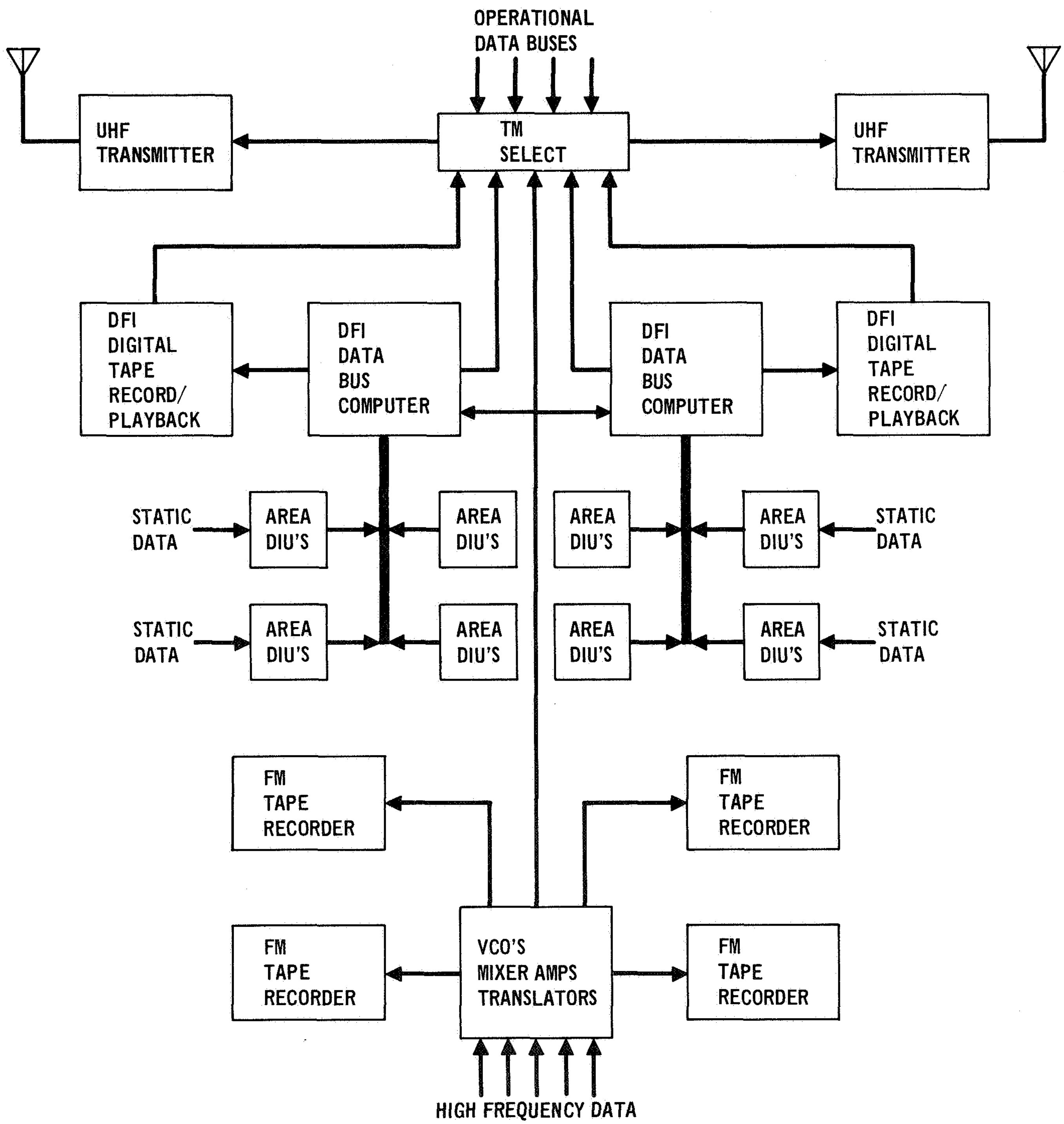


FIGURE 7.5–2

The Digital system consists of two data busses, using separate but identical computers and digital interface units (DIU's) as the operational data bus system. Both data busses are transmitted on each RF link and stored on each of 2 magnetic tape recorders. The separate DFI data bus approach using operational data bus hardware was selected as a compromise of the factors involved. The operational data management system has more than sufficient spare and growth capacity to absorb the digital data requirements for the development flights. With this approach, DFI measurements would be added to two of the four operational data busses and those would be transmitted and recorded completely, at the 1 Megabit rate.

Since this approach would require no additional hardware development and qualification and no additional data bus installation designs, it appears very attractive from a hardware cost viewpoint. Only one specification need be written and administered, test procedures and equipment become identical, and checkout and maintenance of only one system is required.

Combining the DFI and operational digital data functions in this manner does present some possible problems, primarily from an operational viewpoint. One major consideration is the impact the DFI would have on the operational software package. An informal study by the software group indicates that this impact is minor with the modular software approach and that the additional DFI software would not jeopardize the operational software: however, the level and complexity of re-verification that may be required is the area that could create an intolerable situation causing significant delays in the test program.

It is generally agreed that a reasonable amount of flexibility is desired, in fact required, for an efficient and timely development flight program. The possibility that lengthy re-verification of the complete software package might be required due to simple DFI changes in measurements has led to our recommendation of the separate DFI data bus approach.

By utilizing the same hardware designs, most of the advantages of the integrated data bus are still retained. The commonality of hardware allows a better spares ratio and even allows future use of this equipment in the operational phase of the program with minor refurbishment. Much of the software could also be utilized for DFI or, more likely, a more efficient data bus will be provided through use of a dedicated software package. Things such as data compression, variable programs, including bit rates, sample rates, scale factors, etc., may be incorporated. The DFI data bus can operate at a lower bit rate than the operational bus and the computer can select and format data for the tape recorders and telemetry transmitters to reduce bit packing densities and, in general, ease the digital recording task and to conserve bandwidth and possibly reduce the number of RF links required.

If, somehow, the software verification problem should disappear as the program progresses, and it becomes desirable to utilize the operational data buses, it would be a relatively simple task, from a hardware viewpoint, to accomplish the change. The software impact would have to be evaluated.

The FM-FM subsystem utilizes Constant Bandwidth Voltage Controlled Oscillators (CBW VCO's) with mixer-amplifiers and translators providing composite signals for recording on magnetic tape machines. Selected signals will be transmitted on RF telemetry for real-time display of critical parameters. This system is the same basic design as the FM-FM system designed for development flight testing of current fighter aircraft.

7.5.2.1 Equipment Definition

7.5.2.1.1 Digital Data Bus - The quasi-static information will be acquired via a computer controlled data bus on each side of the vehicle. The computer for each bus will address the DIU's (Digital Interface Units) on the bus and thereby sample the data present in each DIU and forward this data with "time" and synchronization so that the output to the tape recorder and transmitters will be a PCM bit stream compatible with MSFN ground receiving stations and other existing data processing and display facilities at KSC, MSC and FRC.

The actual hardware will be the same design as the operational data bus hardware including the interface circuitry, signal conditioning and, to some extent, the computer and software. A computer with less capability could perform the DFI functions; however, these units can be refurbished after the development flights, as necessary, and used as operational units making it less costly overall.

Some of the DFI data bus characteristics are:

Bit Rate	- 204.8 KBPS
Encoding Resolution	- 8 Bits
Sample Rates	- Variable - computer controlled
Format	- IRIG compatible

The multiplexing and encoding is accomplished in the DIU's as is any required signal conditioning. Each DIU has its own power regulation circuit which provides logic power and reference voltage for the sensors and related circuitry.

7.5.2.1.2 Digital Tape Recorders - The DFI recording requirements are very close to the operational maintenance recording requirements and every effort will be made to utilize one basic design for both machines. Present indications are that this can be accomplished with only a larger reel for longer record time and a high speed playback capability of approximately 5 to 1 ratio to allow "dumping" of data from the Booster after the missions for data analysis.

The recorder concept is for a "sealed" type device with data played back and recorded on a ground machine, as opposed to a unit wherein the reels are removable. In general, this provides a more reliable device and eliminates this source of contamination.

7.5.2.1.3 FM Tape Recorders - These machines are relatively standard instrumentation tape recorders which have been and are now in use for gathering dynamic data on test programs including the F-4 and DC-10 and many others. Some of the general characteristics are:

Number of tracks - 14

Tape width - 1 inch

Reel size - 10.5 inch

Tape speed - 7.5, 15, 30, 60 inches per sec.

Direct record response - Up to 250 KHz

Wide band TM response - Up to 20 KHz

The tape reel is removable on these machines and will be placed on ground machines for playback and processing. The tape could be changed during the mission if necessary; however, it is anticipated that sufficient record time will be available for monitoring the high activity periods such as launch, reentry, etc., so that changing tape in flight should not be required.

7.5.2.1.4 Frequency Division Multiplexing (FDM) System - The FDM portion of the DFI provides the system for monitoring the medium and high frequency data. A flow diagram is shown in Figure 7.5-3. Most of this data is recorded on 14 track, intermediate band, magnetic tape recorders. These machines use 1" wide tape and operate at 7.5, 15, 30 and 60 inches per second. This provides a Direct Record response of 30, 60, 125, and 250 KHz and a wide band FM response 2.5, 5.0, 10, and 20 KHz, respectively.

The FDM system incorporates multiple-channel VCO chassis located at various measurand pickup points throughout the vehicle. Each chassis contains up to six "A" channel (2 KHz) or four "C" channel (8 KHz), IRIG standard CBW NBFM VCO's. The outputs of all VCO's in a chassis are mixed to form a single composite, which is transmitted on a single line to the main instrumentation package. Within this

SPACE SHUTTLE DFI
FDM FLOW DIAGRAM

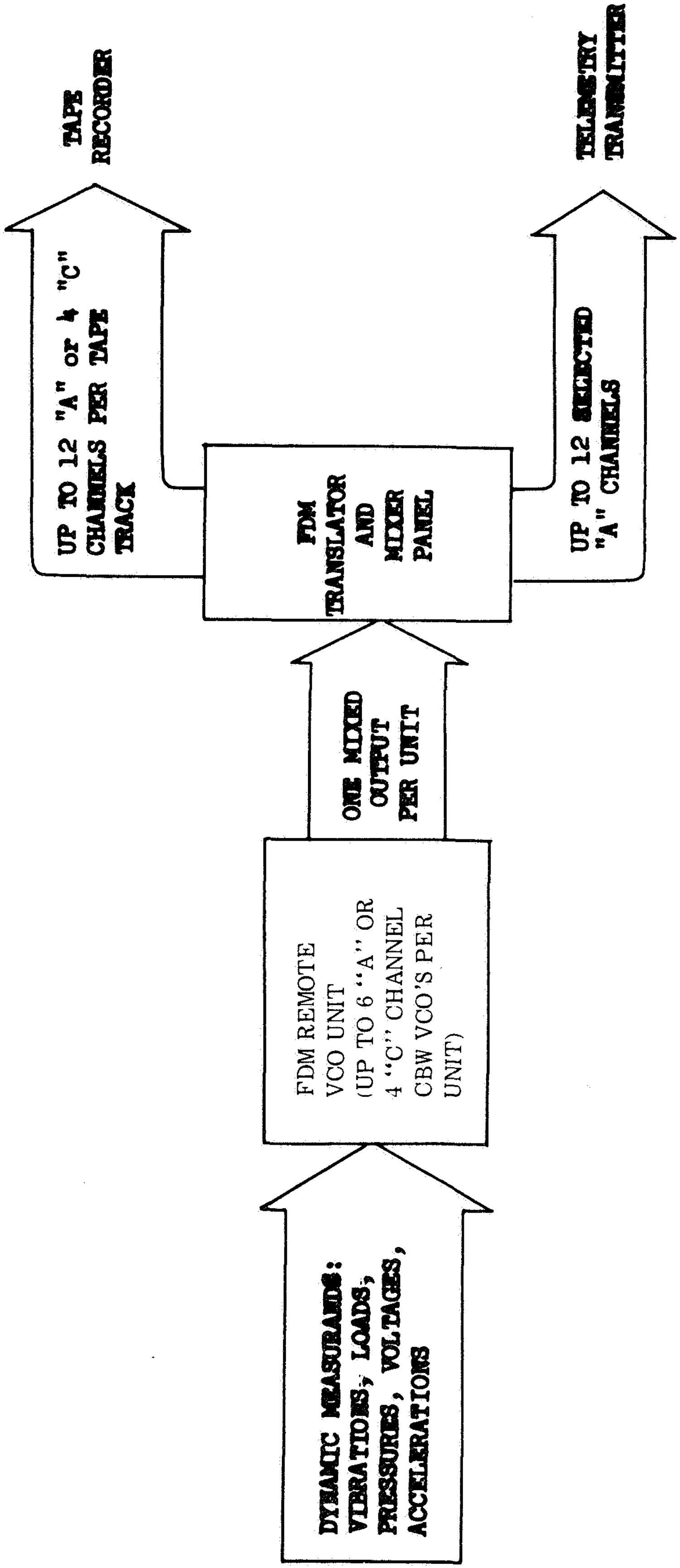


FIGURE 7.5–3

package, the composites from the various chassis are patched to the proper frequency translators and/or mixers. Locating the VCO chsssis remote from the main instrumentation package reduces the size of instrumentation wire bundles, signal pickup wiring length, thereby improving signal-to-noise ratio, and the size of the main instrumentation package.

Frequency Translation - Frequency translation is employed when it is necessary to record (or transmit) two "A" channel VCO chassis on a single tape recorder track, thereby providing twelve 2-KHz (nominal) data channels per track. This configuration is shown in Figure 7.5-4. The use of a constant bandwidth VCO system utilizing frequency translation offers several advantages over a proportional bandwidth system. They are:

a. A reduction of VCO spares costs since only six individual VCO carrier frequencies are required to generate a 12-channel FDM composite.

b. A reduction of tape flutter effects upon the higher carrier frequency VCO channels. Such reduction is derived as follows: A fixed percentage of tape flutter in a CBW FDM system produces increasing percentages of data error in the data channels employing the higher carrier frequency VCO's. This increasing error results from the fact that the percentage of VCO deviation decreases as the VCO carrier frequency increases. A comparison of data errors in a CBW system produced by uncompensated 1% peak tape flutter is displayed in Figure 7.5-5. Tape flutter compensation theoretically reduces all errors of Figure 7.5-5 to zero, but in practice these errors are reduced approximately 30db, or to about 1/30 of the indicated percentages. This limited reduction dictates the use of translation in a high-accuracy CBW system employing magnetic tape recording.

c. A reduction of VCO carrier frequency drift effects. Translated CBW systems employ only the lower VCO carrier frequencies, whereas non-translated

12 CHANNEL IRIG "A" CHANNEL CONSTANT BANDWIDTH
VOLTAGE CONTROLLED OSCILLATOR TRANSLATION SYSTEM

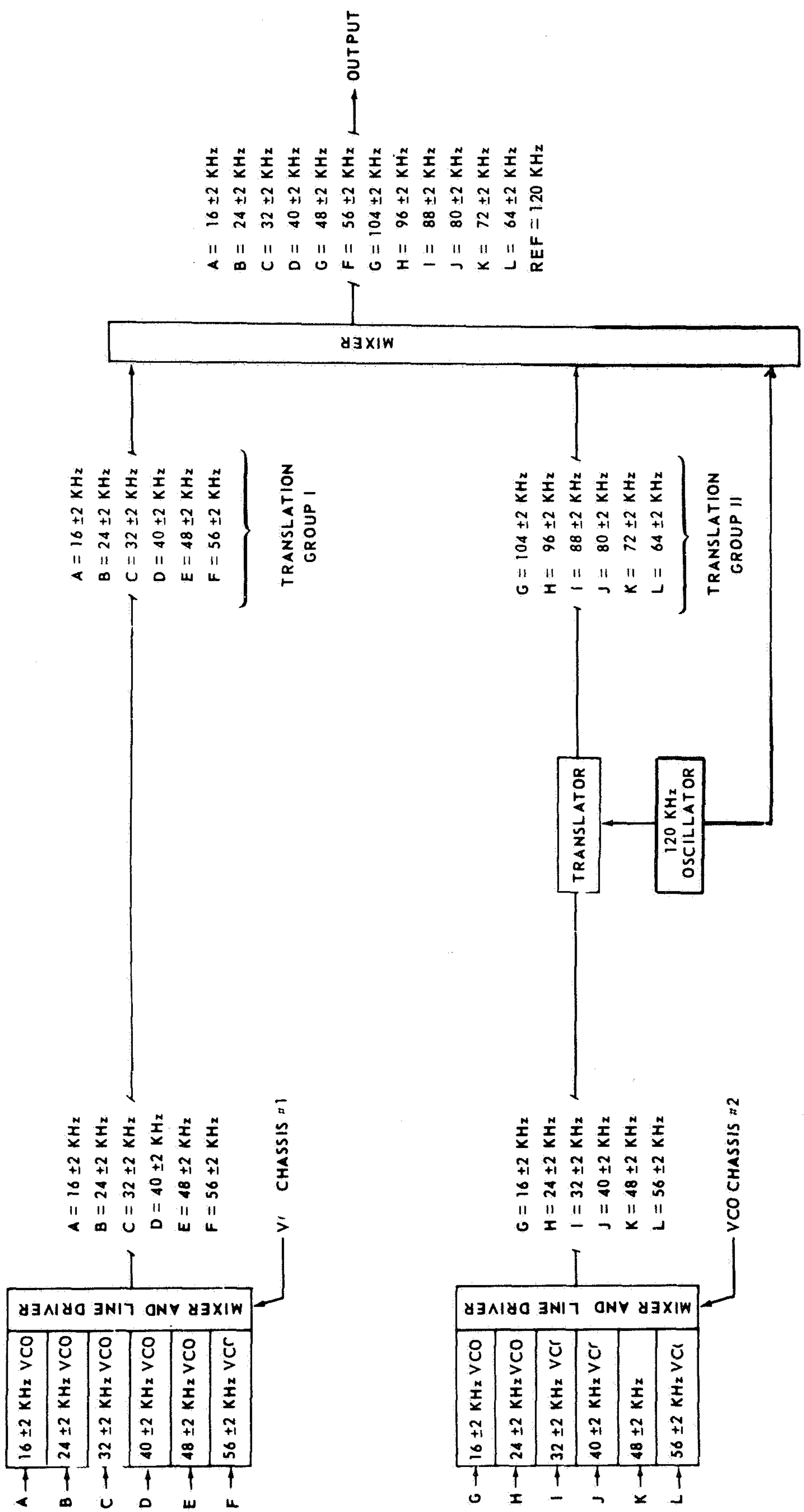


FIGURE 7.5–4

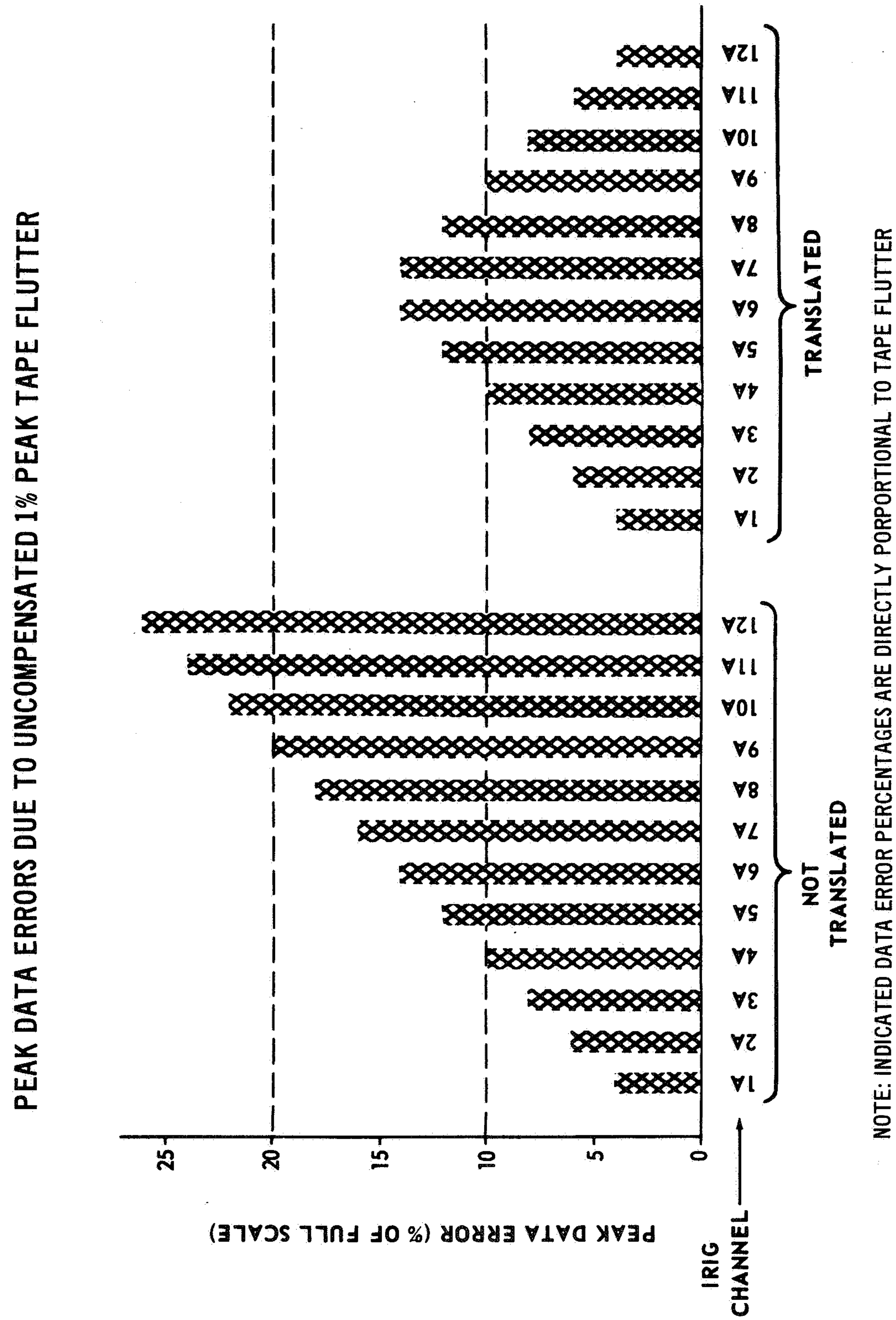

PEAK DATA ERRORS DUE TO UNCOMPENSATED 1% PEAK TAPE FLUTTER
PEAK DATA ERROR (% OF FULL SCALE)
0
5
10
15
20
25
IRIG CHANNEL
1A
2A
3A
4A
5A
6A
7A
8A
9A
10A
11A
12A
NOT TRANSLATED
TRANSLATED
NOTE: INDICATED DATA ERROR PERCENTAGES ARE DIRECTLY PORPORTIONAL TO TAPE FLUTTER

FIGURE 7.5–5

CBW systems also employ a number of VCO's operating at high carrier frequencies. Figure 7.5-6 displays a comparison of data errors in both a translated and non-translated CBW system produced by 0.1% (of VCO center carrier frequency) VCO frequency drift.

In order to diminish any system errors resulting from a difference in the translation and detranslation frequencies and tape recorder flutter, the translation frequency is recorded on the same tape along with the VCO composite and used as the reference in detranslation.

FDM on Magnetic Tape Recorder - Both "A" channel and "C" channel VCO's are employed. A summary of system capacities is presented in Figure 7.5-7.

Although "A" channel and "C" channel VCO's utilize the same basic FDM equipment (VCO chassis, FDM patch panel, translator/mixer chassis, and reference/translation oscillator chassis), their operational configuration in this equipment differs.

a. "A" Channel CBW on Magnetic Tape - Figure 7.5-8 displays the "A" channel system. Included is a chart of system capacities at various standard tape speeds.

b. "C" Channel CBW on Magnetic Tape - Figure 7.5-9 displays the "C" channel system. Included is a chart of system capacities at various standard tape speeds. Details of the translator/mixer chassis and reference/translation oscillator chassis are presented in Figure 7.5-10.

7.5.2.1.5 Telemetry Transmitters - The RF link for the DFI telemetry will use the operational transmitter basic design with adjustments for modulation sensitivity as required. Two transmitters are used in each vehicle, primarily to transmit the two DFI data buses, both buses being transmitted on each RF link; however, a selecting circuit is provided should it be desired to transmit the

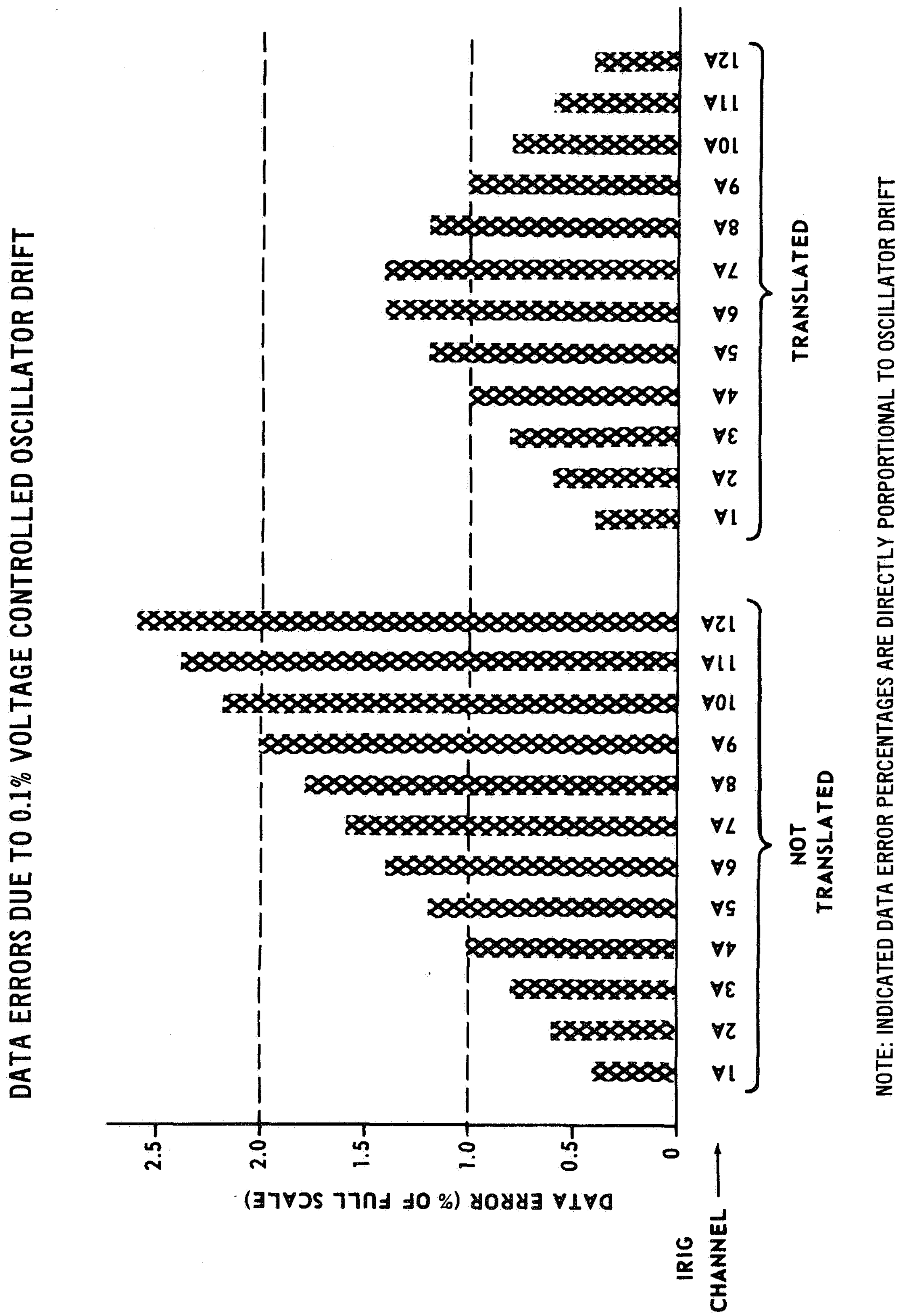

DATA ERRORS DUE TO 0.1% VOLTAGE CONTROLLED OSCILLATOR DRIFT
DATA ERROR (% OF FULL SCALE)
0
0.5
1.0
1.5
2.0
2.5
IRIG CHANNEL
1A
2A
3A
4A
5A
6A
7A
8A
9A
10A
11A
12A
NOT TRANSLATED
TRANSLATED
NOTE: INDICATED DATA ERROR PERCENTAGES ARE DIRECTLY PORPORTIONAL TO OSCILLATOR DRIFT

FIGURE 7.5–6

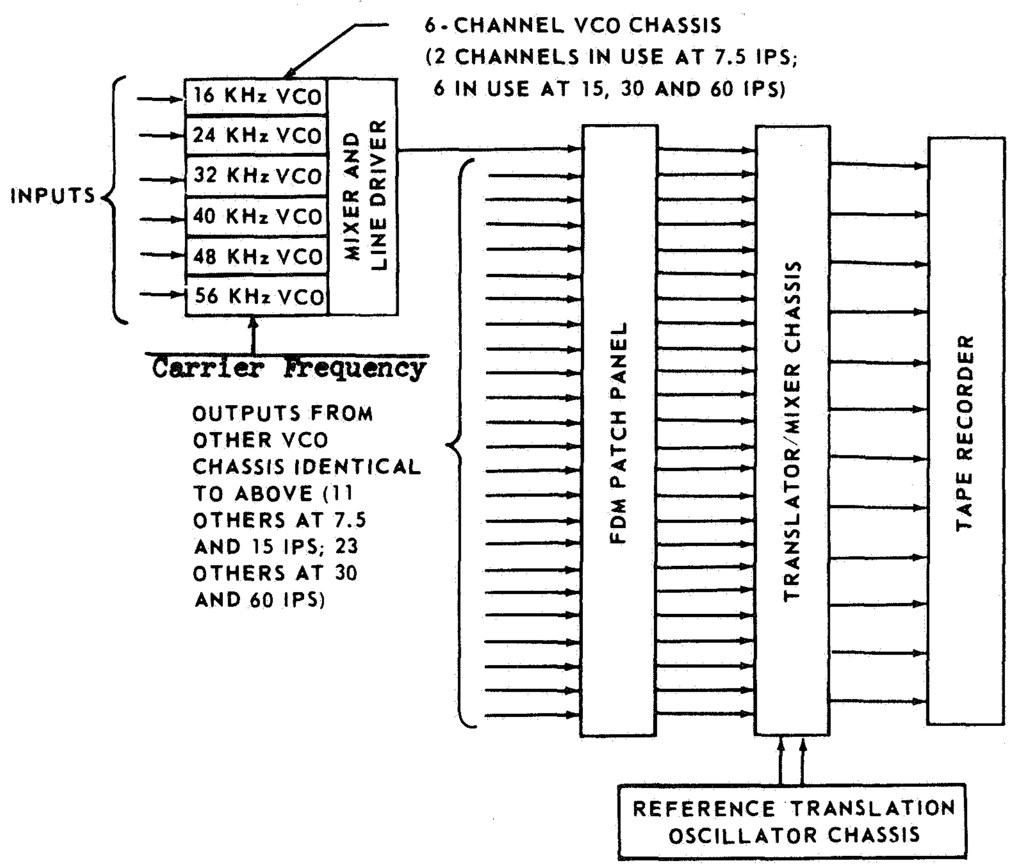
SPACE SHUTTLE DFI
FREQUENCY DIVISION MULTIPLEX SYSTEM CAPACITIES

(CONSTANT BANDWIDTH NARROW-BAND FREQUENCY
MODULATED VOLTAGE CONTROLLED OSCILLATORS)

TAPE SPEED, IPS	CHANNELS	MAXIMUM QUANTITY OF INPUTS TO EACH VCO CHASSIS	MAXIMUM QUANTITY OF VCO CHASSIS WHICH MAY BE RECORDED	MAXIMUM QUANTITY OF TAPE TRACKS IN USE	MAXIMUM QUANTITY OF DATA CHANNELS PER TAPE TRACK	MAXIMUM QUANTITY OF DATA CHANNELS RECORDED	MAXIMUM DATA CHANNEL FREQUENCY (KHz)	MAXIMUM TAPE RUN TIME (MINUTES)	FLUTTER COMPENSATION FREQUENCY (KHz)
7.5	"A"	2	12	12	2	24	2	120	30
	"C"	0	0	0	0	0	0	120	30
15	"A"	6	12	12	6	72	2	60	60
	"C"	0	0	0	0	0	0	60	60
30	"A"	6	24	12	12	144	2	30	120
	"C"	2	12	12	2	24	8	30	120
60	"A"	6	24	12	12	144	2	15	120
	"C"	4	12	12	4	48	8	15	240

FIGURE 7.5–7

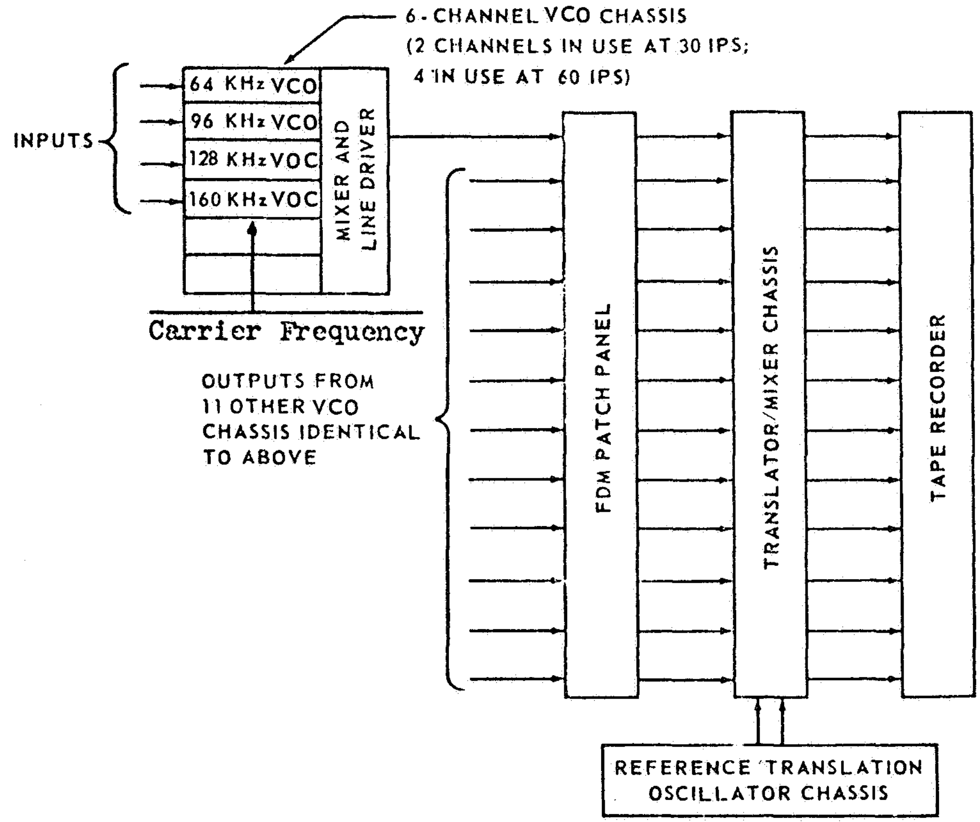
IRIG "A" CHANNEL CONSTANT BANDWIDTH FREQUENCY DIVISION MULTIPLEX SYSTEM



SYSTEM CAPACITIES		MAXIMUM QUANTITY OF INPUTS TO EACH VCO CHASSIS	MAXIMUM QUANTITY OF VCO CHASSIS WHICH MAY BE RECORDED	MAXIMUM QUANTITY OF TAPE TRACKS IN USE	MAXIMUM QUANTITY OF DATA CHANNELS PER TAPE TRACK	MAXIMUM QUANTITY OF DATA CHANNELS RECORDED	MAXIMUM DATA CHANNEL FREQUENCY (KHz)	MAXIMUM TAPE RUN TIME (MINUTES)
TAPE SPEED	7.5 IPS	2	12	12	2	24	2	120
	15 IPS	6	12	12	6	72	2	60
	30 IPS	6	24	12	12	144	2	30
	60 IPS	6	24	12	12	144	2	15

FIGURE 7.5–8

IRIG "C" CHANNEL CONSTANT BANDWIDTH FREQUENCY DIVISION MULTIPLEX SYSTEM



SYSTEM CAPACITIES		MAXIMUM QUANTITY OF INPUTS TO EACH VCO CHASSIS	MAXIMUM QUANTITY OF VCO CHASSIS WHICH MAY BE RECORDED	MAXIMUM QUANTITY OF TAPE TRACKS IN USE	MAXIMUM QUANTITY OF DATA CHANNELS PER TAPE TRACK	MAXIMUM QUANTITY OF DATA CHANNELS RECORDED	MAXIMUM DATA CHANNEL FREQUENCY (KHz)	MAXIMUM TAPE RUN TIME (MINUTES)
TAPE SPEED	7.5 IPS	0	0	0	0	0	0	120
	15 IPS	0	0	0	0	0	0	60
	30 IPS	2	12	12	2	24	8	30
	60 IPS	4	12	12	4	48	8	15

FIGURE 7.5–9

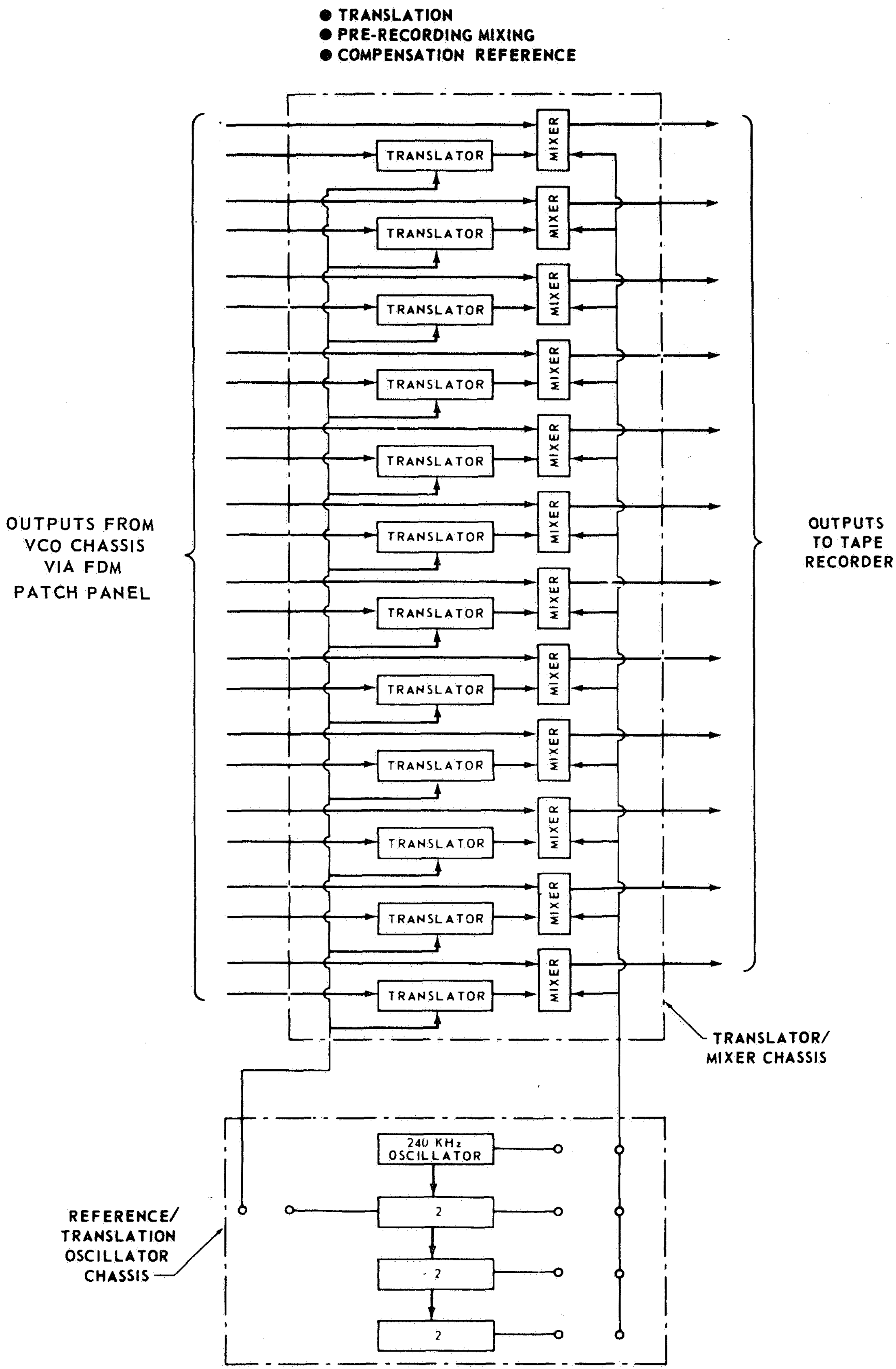

● TRANSLATION
● PRE-RECORDING MIXING
● COMPENSATION REFERENCE
OUTPUTS FROM VCO CHASSIS VIA FDM PATCH PANEL
TRANSLATOR
MIXER
OUTPUTS TO TAPE RECORDER
TRANSLATOR/ MIXER CHASSIS
240 KHz OSCILLATOR
2
2
2
REFERENCE/ TRANSLATION OSCILLATOR CHASSIS

FIGURE 7.5–10

traffic on any operational data bus, playback of the DFI tape recorder, or an FM-FM multiplex signal.

7.5.2.1.6 DFI Power - To provide for the remote possibility that the vehicle should lose all power, a back-up battery source will be implemented to provide telemetry signals for a few minutes after loss of the power buses. A trickle charge will be maintained whenever the buses are on. While it is very unlikely such a catastrophe may occur, the possibility of having no data with which to evaluate such a situation is extremely depressing. It is on this basis that the back-up power is justified.

7.6 Predelivery Flight Acceptance Tests - As each booster completes its portion of the horizontal and/or vertical flight test program it is refurbished to the extent necessary to attain an operational vehicle status. As an integral part of this refurbishment activity, acceptance tests are performed to certify these vehicles for operational use.

7.6.1 Test Requirements - Test requirements for predelivery flight acceptance tests are described in Figure 7.6-1.

PREDELIVERY FLIGHT ACCEPTANCE TEST REQUIREMENTS

TEST REQUIREMENTS	JUSTIFICATION
Prior to final delivery of the booster to the NASA for operational use, acceptance tests are required following post flight test refurbishment.	Required to certify the operational status of each booster.

FIGURE 7.6-1

7.6.2 Test Approach and Rationale - Acceptance tests to certify each booster for operational use will be performed as an integral part of the post flight test refurbishment activity. The depth of the testing required is a direct function of the refurbishment applicable to a particular vehicle. Typical refurbishment activities will include: the removal of flight test instrumentation and special components or subsystems installed for the flight test program, updating of the vehicle to an operational configuration, and inspection, maintenance, and revalidations.

Applicable portions of the tests and procedures as previously described in

Paragraph 7.3, Ground Acceptance Tests, will be performed during and after refurbishment.

In addition, a series of acceptance test flights will be flown to check horizontal flight characteristics. These flights will exercise the booster in its horizontal flight regime. The flights will check the horizontal flight operation of the navigational system, the guidance system (area navigation and automated landing), and other subsystems. Discrepancies noted will be corrected, revalidated by ground test and flight tested on another check flight, if necessary. These flight tests will be comprehensive in nature and will utilize information obtained from development and verification flight tests for test criteria.